The TREND IN ENGINEERING

at the University of Washington

In this issue:

PESTICIDES: A NEW SOURCE OF WATER POLLUTION

A STUDY OF THE BEHAVIOR OF RIVETS

THE ANALOG AND DIGITAL COMPUTER IN ENGINEERING EDUCATION

A STUDY OF THE POST-WELD THERMAL TREATMENT OF AN ALUMINUM-COPPER ALLOY

TWO-DIMENSIONAL TURBULENT MIXING BETWEEN A FREE STREAM AND A CONFINED PARALLEL SLOT JET

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THE ENGINEERING EXPERIMENT STATION

THE ENGINEERING EXPERIMENT STATION of the University of Washington, which was established in December, 1917, performs a three-fold function:

1) It stimulates, promotes, and coordinates investigations and research in all fields of engineering.
2) It publishes results of significant research achievements.
3) It provides opportunities through Graduate Research Assistantships for engineering students to extend their professional education while pursuing a course of study leading to the M.S. or Ph.D. degree.

For administrative purposes the work of the Station is organized under six divisions. All research is carried on in the various academic departments of the College of Engineering under the supervision of the department faculties.

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WHAT'S THE PRICE OF INFORMATION UNLIMITED?

As if he hadn't already enough troubles to worry about, the engineer is now being urged to shoulder another one, the swelling information problem. This is a worldwide increase in scientific and technical publication so big that American and British critics think it may overtax our capacity to handle it. Publications people at Chrysler Corporation call the upsurge an "information explosion"; and, since it is a child of the nuclear and space era, we are likely to credit almost any of the bloated statistics forecasting its future. If the forecasts are accurate, won't the engineer be forced to increase his study hours correspondingly?

Whether or not he can visualize a violent eruption of journals and reports, anyone can find evidence of increases. Like some of the critics, he can also ask how big a proportion of the publication is worth what it costs and will cost. Confronted with the problem of quantity, cost, and quick availability, the engineer may nod and answer, "That's the scientists' alley—let them play there"; but the odds indicate that he cannot avoid being swept into the flood also. All the evidence points to one conclusion: each of us will have to pick up more theories and facts quicker than ever before. The real question is how to do it economically.

A simple test indicates the trend. Take a word or phrase from a hatful of concrete technical or scientific words and see how much space it got in a periodical index last year, compared with its coverage in 1939 and 1949. For example, in 1939 *Vacuum Tubes* occupied less than 5½ pages in the *Engineering Index;* in 1949—when it was promoted to *electron tubes*—it took 10 pages; and in 1959, 14½ pages. It could have demanded more in 1959 if *Transistors,* which appeared in the 1948 *Index*, had not begun taking more pages every year. Another test anyone can try is to judge how well he keeps up with the new words minted every month. How many of us can promise to know enough about a newly named product to use it profitably as soon as occasion arises, a product like the tunnel diode, say, or an epoxy resin?

The problems that come with immense harvest piles of information received attention before the first atomic bomb burst. For instance, in 1944 Fremont Rider projected the contents of the Yale Library for the end of another hundred years of normal growth as 200,000,000 volumes, 6000 miles of shelves, and ¾ million catalog drawers, the books growing by 12,000,000 volumes a year. Since then, various groups have studied the problems of spectacular growth, particularly the difficulties of circulating scientific information, and have made progress in meeting them. The difficulties are not just quantity, though it is the easiest one to illustrate.

Statistics on the volume of present and future publication are numerous, at least half of them being attempts to indicate the worldwide production. As would be expected, most of them are generalized estimates or predictions that sometimes contradict one another. However, a representative listing should offer a fairly accurate picture of what is ahead of us. The following citations were picked so as to avoid repetition:

This year the world's technical journals will offer 60,000,000 pages of scientific reports; yet the scientific and technical work being done outruns the printing presses, and a larger part of the worthiest developments are buried in hundreds of thousands of classified or proprietary reports. (J. P. Nash, Director of Research, Lockheed Missiles and Space Division.)

Every minute, 2000 pages of books, newspapers, or reports are being published in the world. A chemist trying to keep up with a year's chemical developments would be 850,000 pages behind if he gave the entire year to reading. (News story in the *Baltimore Evening Sun,* as paraphrased in *Technical Survey.*)

Despite technical meetings in aviation and space sciences that cost no less than 258,000 work days and $21,500,000 each year, a study by the Daniel and Florence Guggenheim Foundation questions whether American scientists and engineers are keeping abreast of fast-moving technical developments. (A. P. story, Jan. 11, 1960.)

Estimates made at Chrysler Corporation indicate the "information explosion" will require 66,000 technical writers in this country by 1970, compared to the 35,000 people now employed in the technical-publications industry, which grosses $4,000,000,000 a year. (*Missiles and Rockets*, May 2, 1960.)

The IGY produced enough data in 13 scientific divisions to fill a long line of freight cars. (C. P. Snow, British scientist and novelist.)

New scientific journals will probably increase, worldwide, by 1000 or more a year. (D. Richter citing D. J. Urquhart of the British Department of Scientific and Industrial Research Lending Library Unit.)

At the All-Union Institute for Scientific and Technical Translation, more than 2600 full-time and 26,000 part-time translators are grinding out ½ a million abstracts for the U S. Government. (R. J. Clements.) (A newspaper story indicates translation costs about 2¢ a word and says the Government is buying 80,000,000 words of Russian-to-English per year; thus the translation from Russian evidently costs something like $1,500,000.)

Quantities like these are our biggest barrier to efficient scientific communication. Unfortunately, there are others, five of which deserve mention here: (1) The level of education or scientific sophistication of the reader, which is the great barrier in relaying scientific news to the people; (2) Military and other institutional secrecy; (3) Foreign languages, these being the biggest barrier for the upper levels of scientists, especially in the U. S.; (4) The gap between the theorist and the professional, and the similar one between the professional and the technician or shopman; and (5) The one between industrial management and its professional staff.

Since the urgency of scientific popularization is debatable, perhaps the subject doesn't deserve consideration here. Circumstances indicate that it does. Most engineers are forced to give public relations at least a bow; more pertinently, everyone has seen the unfortunate results of misinterpreted press releases on scientific or engineering endeavors. One lot of evidence indicating that newspaper readers want more and better information—which they can also comprehend in bigger proportion nowadays than they get credit for—appears in a NASW Report, *Science, The News, and the Public.* An opposite stand is taken by M. W. Thistle, Chief of the Public Relations Office, National Research Council of Canada, who thinks mathematical symbols offer the only sound means of communicating current scientific detail.

Thistle insists that whatever gets across the double barriers dividing communicator from audience is probably distorted or false. He classifies scientific material within five levels of difficulty. Carrying a reader from one level to the next is, he says, a difficult assignment. Carrying him ahead farther than the next class above his, as in explaining Einstein in a Sunday newspaper supplement, is as farcical as "declaiming Gaelic poetry to a deaf sea gull." Application of Thistle's chart of difficulty makes laymen of practically all of us. According to the chart only a handful of engineers could comprehend physicist Paul A. M. Dirac, whose top place on the chart represents "advancing science."

Actually, though, Thistle's argument amounts to a sturdy condemnation of scientific romanticizing, for he does admit he favors publishing more of the superior kind of writing and speaking. We must just face up to the fact that too much scientific information is overdressed, especially when it's in a package labelled *Popular Spectacular.*

The second barrier listed here, military and other secrecy, has received abundant attention. Secrecy and science are essentially contradictory, as Conant, Van Allen, and other top men reiterate; yet little has been done to eliminate this barrier. More progress has been made in overcoming the language barrier, though only the mechanical translator now said to be a few years away promises to break through this one economically and efficiently.

The barrier between theorist and professional, or engineer and technician—and similarly the one between management and staff—deserves attention, for it can often be surmounted through directed effort. Seabrook Hull apparently thinks this is the biggest obstacle to swifter progress in critical space-era research and development work. He thinks that we gather an abundance of acquired knowledge, but that it can be put to work efficiently only when the theoriticians find ways of speaking a language the craftsmen and the technicians understand.

All of these barriers are reinforced by the immense stockpiles of publication. Moves toward relieving the problem of quantity have attacked some of the other barriers, especially that of foreign languages; but for the most part these others will be with us always, though individual and collective effort can reduce them.

In one attack upon quantity, real progress has been made. New methods are being used in handling, indexing, scanning, and literature searching. The adaptation of the machine to these tasks is being achieved, so that most engineers have perhaps already made use of the improvement, even though the effects of the new techniques will become apparent only gradually.

Progress is also evident in the growth and efficiency of the abstracting journals and services, which are usually the easiest way to cut through the obstruction of quantity. Improvement is still needed, however, because the abstracting sometimes is a year or more behind the publication of the work; generally, too, the abstracting agencies fail to cover some sources, such as government publications, theses, and trade literature.

As in other respects, the Russians are more than a few jumps ahead of us in science information services. Each Soviet factory boasts its own library; and the information services are centralized in VINITI, which publishes 13 abstracting journals. Coverage of these journals is worldwide, and their output is expected before long to include almost a million articles a year, a mark that should be attained since the procedures are now being mechanized. Russian distribution and reading of American technical literature is known to be rapid. Against this we can set our slim record: we have too few technical libraries, no central information service, and inadequate foreign coverage. Apparently less than one-ninth of the Soviet wordage is translated in this country, only a very little more of it being read in Russian by our specialists. There is also a lag of as much as eight months between receipt of a Russian article and its circulation. In fact, most foreign material is slighted in this country.

Obviously the Russians do not credit the statement sometimes heard here, "It's cheaper to do the work again than to find it in the literature." They are doubtless saving priceless research time by picking up promptly what we offer.

What road, then, should the engineer take, confronted with mountainous piles of information, valuable portions of it in Russian, Chinese, or Polish, as well as Italian, German, French, and Japanese? Clearly he cannot scan an ever-larger portion of it; moreover, doubts are rightly cast on the quality of a considerable part of it. But can he afford to ignore sound theoretical or experimental work only because it was done outside the walls of his own organization? Can he justify ignorance when it means repeating work that has already been completed and documented?

No hasty answer to these questions suffices, and none is needed, for a convincing answer is available. An article by L. W. Ross, "The Information Problem," is available through ESS, Georgia Tech, as a reprint from *Chemical Engineering.* Though aimed at chemical engineers and based partly upon Ross's experience as a design engineer, this article is almost as pertinent for any other kind of engineer.

The answer Ross gives to our questions is, in effect, "No, neither the engineer nor his employer can afford to sidestep the literature search, despite its mounting difficulties." He lays out the best roads to follow in this examination, with strong emphasis upon the usefulness of consultation agencies and information services. He lists several such services and also gives suggestions for the location of translators. The only short cut through the mountains of publication, he indicates, begins with secondary sources (through the abstracts).

Several conclusions grow from a study of Ross's article and from other helpful sources. Barriers to rapid communication cannot be torn down; but they can be crossed, including the biggest one of all, immensity. A central fact is that the masses of information must be searched, culled, and sorted. These are too big a job for any one person, even within his own specialty. Information agencies dealing in abstracts are necessary, both the smaller ones we have and others like them. We need more of them, and we need more up-to-date digests of available information.

Above all, in this country we need a central agency to coordinate the over-all information effort; winnow the total production; and pick up the loose ends like foreign publications, research bulletins, graduate theses, government reports, and papers delivered at conferences. Organizing and operating such an institution would be an effort no bigger than others we have made, no more ponderous than others the Government has shouldered and carried home. It would deserve to be called investment rather than extravagance.

Of course, the researcher would still have the work of secondary searching, followed by plenty of good solid study of primary sources, just as he now has. As we go about this task, the only solace we will ever have is that it could be much more difficult. Sir Lawrence Bragg expresses the idea with English candour: "I confess sometimes to having a feeling of despair when I see the library table groaning under all the periodicals and journals, a doubt as to whether it really is all worthwhile, and I expect many may well have the same feeling. We ought perhaps to take comfort from the prodigality of Nature which showers such masses of papery seeds from the elm each year, and reflect what a small portion of these will ever become young trees. So many of these papers will fall on stony ground, so few will be absorbed into the growing body of science. Here we must recognize, it seems to me, that the solution for successful assimilation does not lie alone in better systems of abstracts, valuable though such schemes are. It lies in that faithful body of devoted workers who read and digest the stupendous mass of literature, and use their judgment to discard what is unimportant and present us with reports, reviews, and summaries which indicate what is valuable in a clear way. It is a tremendous task, like that of extracting the gold from the quartz reefs of the Rand. . ."

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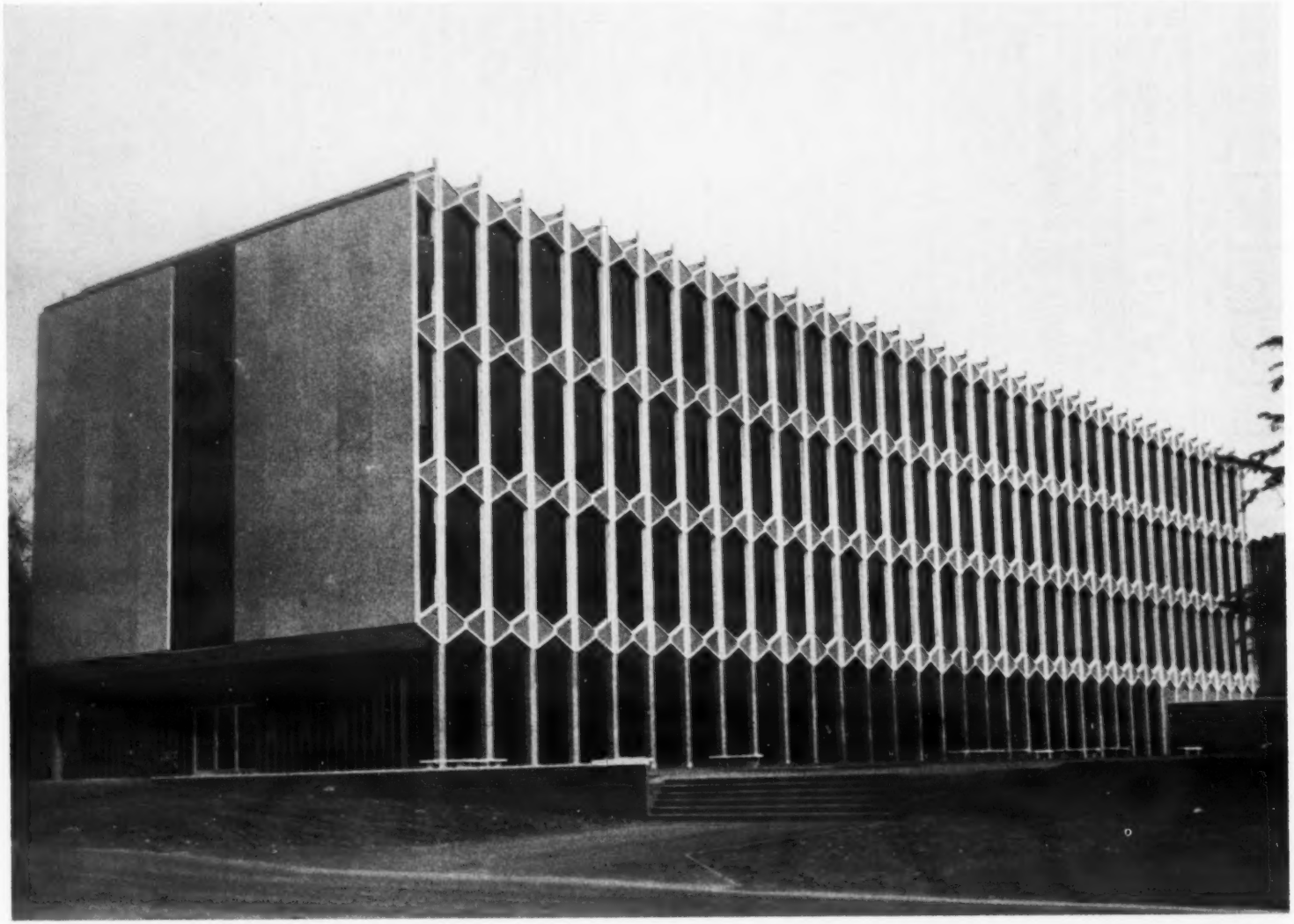

The General Engineering Building: This $1,780,000 structure completed in Jan., 1960, provides new offices, classrooms, and an auditorium. Shown here is one of the two faces formed by over 200 cast-stone window panels designed to help blend Gothic into modern.

Pesticides: A New Source of Water Pollution*

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Recent reports of fish and wildlife kills and of hazardous residues on foods point out the dangers of uncontrolled or improper use of pesticidal chemicals. Synthetic organics, principally DDT, other chlorinated hydrocarbons, metallic derivatives, and organic phosphorus compounds account for approximately half of the pesticides production, which now runs to well over 700 million lb annually. Significant amounts of these substances, together with diluents and carriers such as clay dusts and organic solvents, are finding their way into surface and ground waters.

Pesticides gain access to ground and surface waters through percolation and runoff from treated areas, through drift during application, and in some cases through direct application. Often less than 50% of the material applied to a crop can be found within the treated area a week after application. Some is lost by evaporation and by chemical decomposition; and, significantly, a large amount is carried away in irrigation return flows, in ground waters, and in surface runoff.

During the past 20 years an intensive search has been under way for new and better chemicals for pest and plant control. An ever-increasing number of synthetic organic pesticides (or "synicides") has appeared on the market. More than 200 such substances now enjoy some degree of commercial popularity. The long-range effect of these chemicals on our water resources is essentially unknown at this time. What is clear, however, is that these substances are finding their way in ever-increasing amounts into our natural water resources and that they have destroyed much valuable aquatic life. Several of the more common synicides, such as DDT, can now be detected in community drinking-water supplies.

Little is known regarding the capability of natural purification agencies to cope with these materials. Recent studies at the University of Washington reveal that most synicides are resistant to biological decomposition and that more needs to be known about the persistence and the effects of trace quantities of these complex organics in water. The purpose of this paper is to define and examine this problem in greater detail. To this end the different types and quantities of pesticides used are described, their application and toxicity are discussed, and in conclusion the problem of evaluating and controlling water pollution by synicides is briefly examined.

R. H. Bogan

Principal Pesticides and Their Components

A number of excellent texts on the chemistry and uses of pesticides have been published.[1,2,3,4,5] These chemicals may be divided into three major groups—the inorganics, the so-called "natural" organics (or plant extracts), and the synthetic organics. Table I lists the commercially significant pesticides from the inorganic and synthetic-organic groups. It should be noted that DDT, cyclodiene derivatives, and 2,4-D are currently the best sellers among the synthetic organics. In addition to the toxic chemicals given in Table I are the carriers and diluents that must be employed in formulating the finished preparation. The following is a representative grouping of the common carrier substances:

COMMON PESTICIDE CARRIERS

Solid Diluents
- kaolin
- bentonite
- fullers and diatomaceous earth
- pumice
- gypsum
- limestone
- dolomite
- lime
- sulfur
- ground walnut shell
- redwood bark

Liquid Solvents
- water
- acetone
- heavy aromatic naphtha
- xylene and xylene-types
- aliphatics
  - kerosene
  - mineral spirits

*This article is based on the thesis Mr. Vargas wrote for his M.S. degree in Civil Engineering. It is an introductory article for the subject, which is to receive more detailed coverage in later issues of *Trend*.

TABLE I

COMMON PESTICIDAL CHEMICALS

INORGANIC PESTICIDES		SYNTHETIC ORGANIC PESTICIDES	
Chemical	Per Cent of 1958 Production	Chemical	Per Cent of 1958 Production
Arsenicals	2	Halogenated hydrocarbon insecticides—cyclic	24
Arsenate insecticides		DDT	12½
calcium, lead, zinc, Paris Green		BHC—lindane	2½
Arsenite herbicides and fungicides		DDD	
calcium, lead, zinc, sodium		methoxychlor	
		Cyclodiene insecticides	9
Sulfur and lime-sulfur insecticides	29	aldrin, dieldrin, endrin, isodrin, chlordane, heptachlor, toxaphene	
Copper fungicides and herbicides	8		
Sulfate and sulfate-lime mixtures			
Chlorides		Other cyclic derivatives	
Oxides		Herbicides	8½
		2,4-D	< 6
Mercury compounds	< 1	2,4,5-T	< 1
Chloride insecticides and fungicides		Fungicides	5½
Oxide disinfectants		phenylmercuric derivatives	
		napthenic acid	
Cyanide fumigants	< 1	glyodin	
Hydrogen, mercury, sodium, calcium		Organic Phosphorus insecticides	2
Borate and chlorate herbicides	16	TEEP	
(principally sodium salt)		EPN	
		malathion	< 1
Chromate fungicides	< 1	parathion, methyl parathion	< 1
		systox	
Fluoride insecticides	< 1		
Cryolite and sodium salts		Acyclic fungicides	2
		Thiocarbamates	< 1
		Ferbam, zineb, ziram, nabam	
		Methyl bromide	< 1

diesel oil
fuel oil
stoddard solvents

Emulsifiers

mineral-oil
sodium- and potassium-base soaps
ammonium-casein mixture
blood albumin
bordeaux mixture ($CuSO_4$, lime, and oil)
sulfated and sulfonated petro'eum products
lignon sulfonates
mono and triethanolamine

Synergists

n-isobutyl undecylenamide
piperonyl butoxide
piperonyl cyclonine
ethylene glycol

Emulsifiers, such as the sulfonated petroleum derivatives, lignon sulfonates, blood albumin, and soap, serve also as wetting and spreading agents. Bentonite and other clays, glue, and gelatin also are commonly used adhesives. A number of organics (sometimes referred to as synergists), though not toxic by themselves, when mixed with certain pesticides form a mixture more toxic than the sum of the compounds acting independently.

McAllister lists the number of commercial pesticide compounds used in the United States as follows:

Herbicides	84
Fungicides	67
Insecticides	66
Rodenticides	11
Soil Fumigants	8
TOTAL	236

These are formulated into over 7000 different commercial preparations, as listed in the *Pesticides Handbook*.[7]

Chemical Quantities and Use Trends

The overall use of pesticides shows a substantial yearly increase, but this growth is not uniform among the varieties used. Some decline in popularity, and others grow or maintain a firm position.

Production figures for the synthetic organic pesticides are published each year by the U. S. Tariff Commission;[8] a less comprehensive summary of inorganic agricultural chemicals data is published by the U. S. Bureau of Mines.[9] According to H. H. Shepard, markets statistician for the U. S. Department of Agriculture,[10] the total production of all pesticidal chemicals and related materials—exclusive of dust diluents, solvents, and surface-active agents

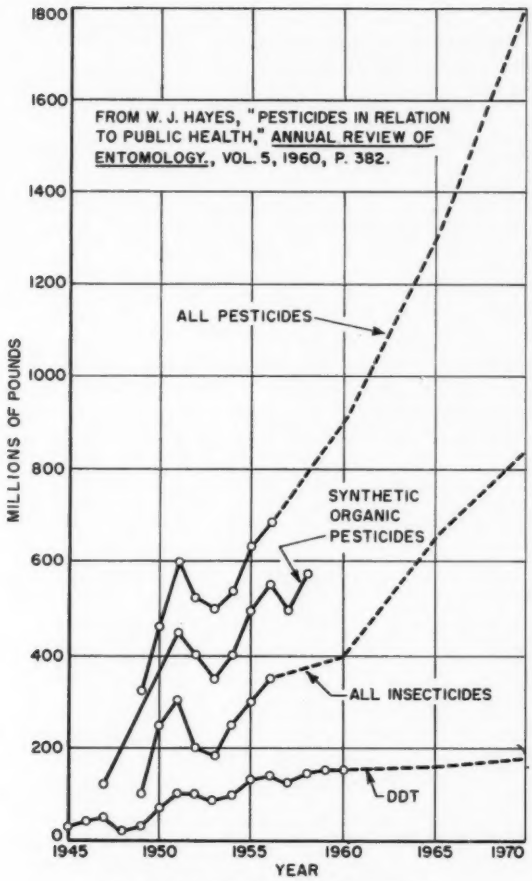

FIG. 1. U. S. PESTICIDES PRODUCTION (Actual and Estimated)

—amounts to approximately 1,000,000,000 lb. annually. This figure includes ground sulfur for dusting and spraying, as well as other inorganic chemicals (such as arsenic and copper compounds, sodium chlorate, and borates). Finished pesticidal preparations containing these chemicals probably amount to 1.5 million tons. Worthy of note is the incorporation of over 500 tons of pesticides in fertilizers for the 1955-56 crop year (mostly aldrin, dieldrin, heptachlor, and toxaphene, plus some 2,4-D, DDT, and arsenicals).[11]

The U. S. Fish and Wildlife Service has disclosed[12] that approximately one-fourth of U. S. cropland is treated annually to some extent with pesticides. Norkus[13] estimates that 25 to 30 million gallons of aromatic solvents are used each year by the agricultural industry. Emulsifier sales have practically doubled in recent years, growing from approximately 8,000,000 lb in 1953 to over 15,000,000 lb in 1959.[14] Solid carriers and diluents (principally clays) are produced

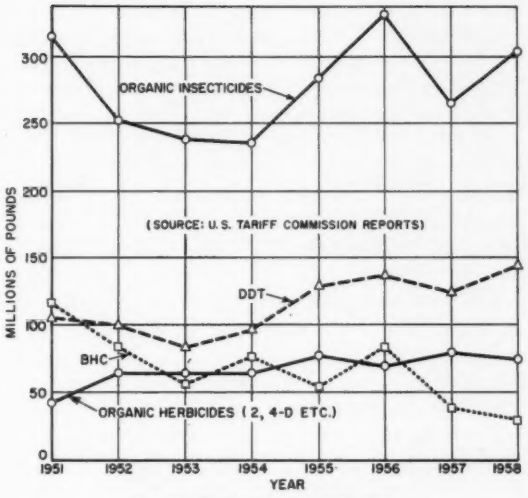

FIG. 2. ORGANIC INSECTICIDE AND HERBICIDE PRODUCTION

at the rate of approximately 500,000,000 lb per year.

An analysis of available data[8,9,10,15] indicates the following trends regarding the production and use of pesticides:

1. Overall figures show an increase in pesticides production amounting roughly to 80,000,000 lb per year. (See Fig. 1.)
2. The biggest gains have been among the synthetic organics, specifically the organic phosphates, 2,4-D, and some chlorinated hydrocarbons, including DDT. (See Fig. 2.)
3. The use of inorganic pesticides is declining, with the possible exception of sodium chlorate.
4. Liquid formulations show a rapid increase in popularity over dusts, although there is increased interest in wettable powders and granulated forms as well.
5. Exports of DDT, organic phosphates, and herbicides account for a significant share of the total U. S. production—over 40% in each case.
6. The continued popularity of DDT and related hydrocarbons appears to come largely from their economy and from familiarity with their use.

Usage and Application

The job to be done will naturally determine the type of chemical employed, viz, weed control (herbicides), fungus control (fungicides), and insect control (insecticides). This in turn will determine to some extent the form and method of application, i.e., whether the pesticide will be applied as a dust, an aqueous solution, or an emulsion and whether aerial spraying or local topical application can or should be employed. Effectiveness, ease of application, and fa-

TABLE II*

COMPARATIVE TOXICITY OF ORGANIC PHOSPHORUS AND CHLORINATED HYDROCARBON INSECTIDIES TO FISH, INSECTS, AND MAMMALS

Compound	Fathead Minnows 96 Hr. TL_m mg\L	Housefly Topical LD_{50} ug\gram	White Rats Oral LD_{50} mg\kg	Solubility in Water (16) mg\L (25°C.)
Organic Phosphorus				
EPN	0.20	1.9	12-40	.....
Parathion	1.4	0.9	13	~20
TEPP	1.7	.....	2	high
Chlorothion	3.2	16.3	880	~40
Systox	3.6	.....	6.2	~100
Methyl Parathion	8.3	1.0	14-42	50
Malathion	112.5	28	1375	145
OMPA	121	.....	10	.....
Dipterex	180	.....	630	130,000
Chlorinated Hydrocarbons				
Endrin	.0013	.....	17.8	<0.1
Toxaphene	.0051	31.0	90	.....
Dieldrin	.016	1.1	46	<0.1
Aldrin	.028	1.6	67	<0.1
DDT	.034	8-21	113	~0.1
Methoxychlor	.035	.....	6000	.....
Heptachlor	.056	1.6	100	.....
Lindane	.056	1.0	125	10
Chlordane	.069	4.0	335	.....
BHC	2.0	.....	1000	5-10

* After C. M. Tarzwell, *Proc. 12th Ann. Conf. SE Assoc. of Game and Fish Comm.*, Oct., 1958, and *Trans. 24th N.A Wildlife Conf.*, 1959.

vorable cost have combined to further restrict the number of chemicals currently employed on a large scale. Government controls have also affected the kind or quantity of some applications. Hence, as indicated by the production data presented in Table I and Figs. 1 and 2, a limited number (fewer than 30, in fact) of synicides account for 80 to 90% of the market tonnage. The major insecticide "best sellers" are those listed in Table II.

Although the chlorinated hydrocarbons are subject to resistance by a greater number of insects, they are so stable as to persist in the soil for several years; on the other hand, the phosphate organics seldom persist over two to four weeks.[16] Thus the type of pesticides employed in any given agricultural area may be expected to differ from one year to the next or perhaps at intervals of two to three years. Yet the persistent residuals may continue to enter drainage waters for some months or years following the use of a particular synicide.

Although many practical methods have been developed for the application of pesticidal chemicals, ranging from hand to air application, a great deal of room for improvement remains. On record are many cases involving the gross overapplication of chemicals[17] and the application for "insurance" against pests that cause little or no damage. Often such insurance is harmful, since the overdose kills many organisms that would have assisted in the control of pests. The amount of toxicant required for effective control is generally less than 1 lb/acre; in many instances as little as 0.1/lb acre would suffice. The amount that must be applied to realize effective residues is markedly influenced by types of formulation and method of application. Figure 3 illustrates the significance of formulation on application efficiency; even more significantly it indicates roughly how large a proportion of applied toxicant may find its way into ground and surface waters.

The one overall restraint working continuously against the overapplication and misapplication of pesticides is legislative action. Government controls result from Congressional effort, which frequently begins with the recommendations of conservation and

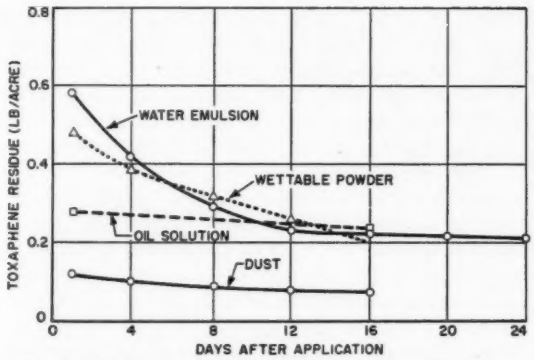

FIG. 3. DEPOSIT OF TOXAPHENE ON ALFALFA HAY AND SUBSEQUENT DECLINE IN RESIDUE CONCENTRATION

Insecticide applied at 2 lb/acre in four different formulations (From J. W. Laakso and L. H. Johnson, "Residue Deposits on Alfalfa from 4 types of Formulation," *Montana Agr. Exp. Sta. Bull.*, Vol. 461, 1949, pp. 5-15)

public-health officials. One such control measure, the Federal Insecticide, Fungicide and Rodenticide Act, has two important provisions:

1. All products involved in interstate commerce must be registered with the U. S. Department of Agriculture; the percentage of active and inert ingredients must be stated.
2. Data must also be provided that show the effect of both short- and long-term exposures to varying amounts of residues and that give directions for use, warning and antidote labels, and identifying colors.

Another measure, the Miller Amendment to the Federal Food, Drug and Cosmetic Act, passed in 1954, requires that tolerances be established for pesticidal residues on foods.

Recent Findings in Pesticide Toxicology

Studies of the toxic properties of pesticides are sufficiently complicated when confined to the work they are intended to do. When the study is directed at the effects upon the higher animals, particularly effects coming through pesticide pollution of water, the task becomes even more complex. This section evaluates the difficulties and surveys the background of recent knowledge available.

The potential of a substance as a poison depends on its chemical constitution and upon its ability to contact living things. Quite often, persistence in the surrounding medium will modify or determine the toxic effects. Persistence is a function of many variables, such as chemical properties (boiling point, vapor pressure, tendency to hydrolyze or react with various chemicals, etc.), cultivation practices, soil type (porosity, alkalinity, adsorption properties, etc.), temperature, humidity, and susceptibility to biological action.

A point often overlooked in evaluating residues is the means used in making the determinations. One school of thought holds [18] that bio-assays (which determine the power of a pesticide by testing its effect upon animal life) give a more realistic assessment of residues than chemical assays. The reasoning is that chemical changes, which often occur in the field, may affect the potential toxicity of the residue. For example, bio-assays of aldrin and heptachlor after soil application give higher residue estimates than chemical assays. From this, one is led to believe that some compounds form more toxic derivatives that do not show up in specific tests for the parent chemical. Conversely, bio-assays of some compounds (e.g., lindane) give lower residue values. Considerable variation in toxicity level has been reported for several of the more common pesticides.[19]

Interpretation of bio-assay data is a difficult business at best; however, the evaluation of biological response in the field is equally difficult and highly speculative in character. For example, one interesting case involved the killing of fish in a pond treated with 2,4-D for weed control.[20] Though the evidence pointed to chemical poisoning, investigation revealed that the fish kills resulted from oxygen depletion caused by decaying weeds.

Tarzwell[19] made an interesting comparison of the toxicity values of some important pesticides tested upon several animal species. Some of his data, reproduced in Table II, show the chlorinated hydrocarbons to be considerably more toxic to fishes than the organic phosphorus compounds. No such pattern is evident from the data on insects and rats. The reason for the difference may be that many of the phosphorus insecticides are subject to hydrolysis into less-toxic substances, and are therefore a lesser threat to fish. Although most chlorinated hydrocarbons are sparingly soluble in water, their solubility is still considerably greater than the 96-hr TL_m values reported by Tarzwell and his associates. Significantly, the mineral composition of the water appeared to have little effect on toxicity. Emulsion and acetone formulations were found to be the most toxic.

In general, the chlorinated hydrocarbons, with the exception of BHC and methoxychlor, tend to be stored in the body. All of these chemicals are stable in the field and sparingly soluble in water, indicating that they are a potential hazard to consumers of products treated with them. The organic phosphates appear to be more toxic to man than the chlorinated hydrocarbons. The metabolic fate of most of the common organic pesticides in man is poorly understood; moreover, the physiological significance of continuous exposure to trace amounts of these chemicals is largely unknown.

A Survey of the Effects on Water Resources

As Tarzwell and others have pointed out,[19,20,21] the use of over 1.5 million tons of pesticidal formulations each year may have a serious pollutional effect on our water resources. In many major rivers, including the Mississippi, Missouri, Illinois, Detroit, and Columbia, DDT has been found in concentrations approaching the toxic level for fish (1 to 20 ppb). Fish kills have been reported with increasing frequency. The appearance in drinking-water supplies of various pesticides in concentrations ranging from 1 to 5 ppb is cause for concern by health officials because the physiological significance of long-term exposure to such residuals is still unknown.

Available production statistics suggest that the annual tonnage of pesticides employed throughout the United States will more than likely double during the next 10 years. It also appears that the synthetics (or synicides) will make up better than 90% of the organic pesticides in use by 1970. Barring a major technological breakthrough in pesticides development, the so-called "best sellers" of today will likely continue to dominate the market. There undoubtedly will be some shifting about in preference and popularity, but on the whole some 30 or so toxicants, mainly chlorinated hydrocarbons, will apparently constitute the bulk of the market. Trends in usage and formulation suggest that most of these toxicants will ultimately appear in the waters drained from most agricultural areas. Thus evaluation of fish kills and similar biological insults will become all the more difficult and uncertain.

Attention also should be diverted to the large volumes of diluents, solvents, and emulsifiers, which often account for over 90% by weight of commercial pesticides preparations. Many of the solvents employed, such as the petroleum derivatives, are known to be highly toxic, even in very small concentrations. Obviously the hazards attributed to many pesticides may be compounded several times through the use of other toxic ingredients in the various formulations.

The physical and chemical properties of a pesticide will influence its capacity to gain entrance to surface and ground waters and so affect the concentration of this material likely to be encountered. Thus, for example, low-solubility substances such as the chlorinated hydrocarbons will naturally be encountered in very low concentrations, generally on the order of 10 to 100 ppb and less. A number of insecticides, notably the organic phosphorus synicides, are relatively unstable, being susceptible to moderately rapid hydrolysis; thus they quickly lose their identity and influence. Hence the highly stable substances like the chlorinated hydrocarbons will continue to appear in surface waters for weeks or months following their use. In fact, reports indicate that some soils have retained sufficient insecticide residues as to remain toxic to fish from one spraying season to the next.

But the knowledge we have is too often unobjective or difficult to evaluate conclusively. Very little is yet known about the fate of pesticides once they enter natural bodies of water; and the reports describing fish kills attributable to pesticides are generally vague and uncertain. Reliable informative reports on actual field conditions have only recently begun to appear in the literature. Another difficulty is the lack of simple tests for measuring traces of organics potent enough to be toxic to fish. Bio-assays and chemical tests often give conflicting results on the presence of toxic substances. Though bio-assays are useful in that they are often the only means of determining the toxicity of a given water sample, chemical tests may be the only means of determining the specific nature of the pollutants involved. Thus, while the biologist theorizes that a pesticide or an industrial waste is poisoning the biota, several types of toxicants from a variety of sources may be acting in concert to produce the biological response observed. Interpretation of direct chemical analysis may be equally vague owing to the presence of a number of substances along with the trouble-causing toxicants, including in some cases their degradation products.

Once a pesticide molecule reaches open water, a number of things may happen: it may be adsorbed on silt and the like and be deposited for a time on stream and lake bottoms; it may become involved with various types of aquatic life, the result being either drastic or indifferent; or it may be subject to biological attack and subsequent degradation. This last possibility is vitally important, for if a potentially troublesome substance is susceptible to microbial destruction then natural self-purification agencies can function to rid a water of the material. In the case of most naturally occurring organics, microbial attack is generally rapid and thorough; unfortunately, many synthetic organics are highly resistant to biochemical degradation. Until recently little was known regarding the biochemical degradation of pesticides. At present R. W. Okey and R. H. Bogan are investigating this problem in the University of Washington Sanitary Engineering Laboratory.

Most of the commonly used insecticides appear to be resistant to biological degradation. Important exceptions are malathion and Thanite, which appear to be more susceptible to biochemical degradation. Halogen substitution and the presence of heavy metals appear to act as important inhibitors of oxidation.

Most of the commonly used fungicides and herbicides, notably the dithiocarbamates and phenoxyacetic acid groups (2,4-D, 2,4,5-T, and their deriva-

(Continued on page 30)

A Study of the Behavior of Rivets

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N. C. Vasishth

The conventional approach to the design of riveted joints follows closely the line adopted by Sir William Fairbairn more than a hundred years ago. This design method considers the load to be equally distributed among all the rivets. The working strength of the riveted joint is determined by the sum of ultimate strength of each rivet divided by a factor of safety. It is, however, common knowledge that at working levels the load is not carried equally by all the rivets constituting a joint. Recently, various experimental and theoretical studies have been made of the elastic deformation of the rivets and plates.

These studies do not take into account the fact that in a large riveted joint only some of the rivets act in bearing, and that present-day riveting practices result in gaps around the rivets and a clamping force in the shank of the rivets, which affect the load carried by each rivet. There is a concentration of stresses around the rivet holes, a deformation of rivets and plates in bearing, and a certain amount of transfer of stresses caused by friction between plates. In the study described here, these factors were investigated experimentally by inspecting the individual rivets, rivet holes, and cover plates of a full-sized plate girder. In most cases the data obtained in this unusual study had to be organized and interpreted indirectly, as explained in this article.

The Specimen and the Plan of Investigation

The specimen used for the study was a full-sized plate girder, designed for a span of 56 ft and a two-point load of 350k applied 14 ft apart. The test, which was sponsored by the Bureau of Public Roads and the Washington State Council of Highway Research, was carried out in the structural research laboratory of the University of Washington under the guidance of Dr. Desi D. Vasarhelyi. A more detailed account of these tests is recorded elsewhere.† For the purpose of this article, it suffices to say that the specimen had been loaded to 2.13 times its design load, prior to unloading, before this investigation was taken up.

This specimen had 880 rivets connecting the flange angles to the web and cover plates. From these, 25% were inspected. The inspection aimed at studying some of the features mentioned earlier; it was carried out in the following order:

Study of Rivets and Plates. An investigation was made of how well the rivets filled the holes and of the location of gaps between the shanks of the rivets and the corresponding holes in the cover plate. Some of the rivets were also knocked out of the plates, and the surfaces of both the rivet and the hole were examined under a microscope.

Estimation of Clamping Force. An attempt was made to estimate the clamping force exerted by the rivets on the plates.

Study of Rivets and Plates

The location of specimens used for this study is shown at the top of Fig. 1. Four specimens, A, B, C, and D, were used for the study, out of which specimens A, B, and C were taken from portions of

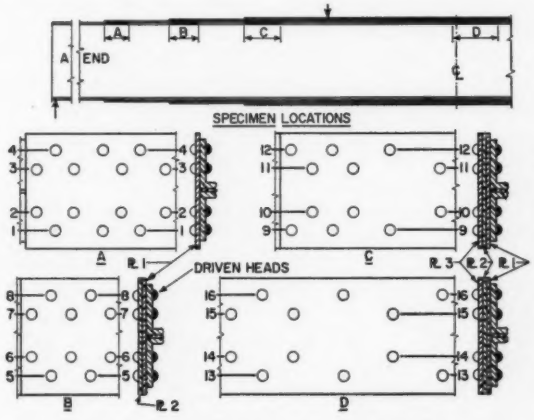


FIG. 1. LOCATION OF THE FOUR SPECIMENS AND OF THE SAW CUTS THROUGH RIVET ROWS

*Mr. Vasishth, who received his M.S. degree in Civil Engineering in March, 1960, is now an engineer with Moffatt, Nichol and Taylor of Portland, Ore. This article is based upon studies of riveted joints he made at the University with the direction and assistance of Desi D. Vasarhelyi, Associate Professor of Civil Engineering.

†"An Experimental Investigation of the Behavior of a Riveted Plate Girder with a Thin Web," unpublished report to ASCE-AASHO Task Committee on Plate Girders, Aug., 1959.

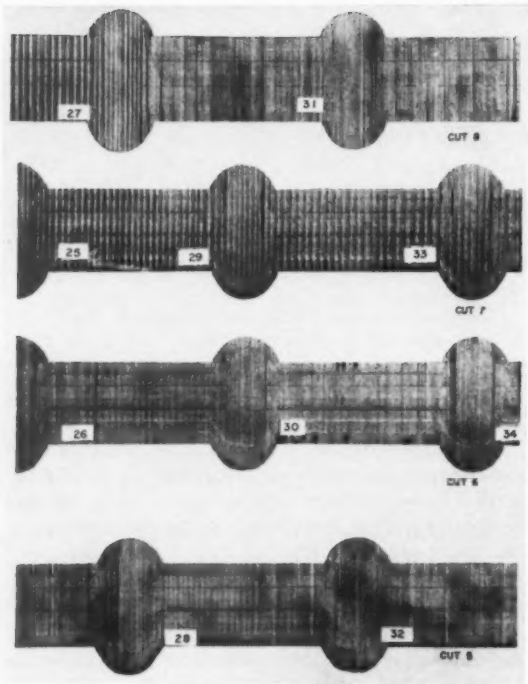


FIG. 2. RIVETS IN SPECIMEN B (FLANGE)

the flange where cover plates are cut off. These specimens included the first few rows of rivets where appreciable slip was anticipated and observed. Specimen D was taken from between the load points, and hence from the zone of no shear. The specimens were cut from the plate girder by making flame cuts along the web and saw cuts along the flange.

For the purpose of this study, saw cuts were made parallel to the web and passing through the various rivet rows connecting the flange angles to the cover plates. These cuts are shown in Fig. 1, as Cut 1 to Cut 16. Each cut passed through the center of the rivet, revealed sections of the rivet lying in the cover plates, and showed gaps along the shank of the rivet wherever they existed. A typical section is shown in Fig. 2. In this way each specimen yielded four cut sections for examination.

The inspection of Specimens A, B, C, and D containing the rivets revealed gaps of varying sizes along the length of the rivet shank. In general, observation showed that gaps varying in magnitude from about 0.003 in. to 0.03 in. exist on both sides of the shank of the rivets at the manufactured head. The gaps toward the middle of the rivet were usually on one side only. Those at the driven head were less than on the remaining part of the rivet, and in some cases were absent.

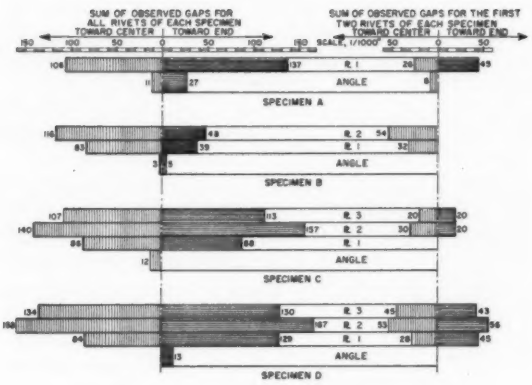

SUM OF OBSERVED GAPS FOR ALL RIVETS OF EACH SPECIMEN
TOWARD CENTER | TOWARD END
SUM OF OBSERVED GAPS FOR THE FIRST TWO RIVETS OF EACH SPECIMEN
TOWARD CENTER | TOWARD END
SCALE, 1/1000"
ANGLE
SPECIMEN A
SPECIMEN B
SPECIMEN C
SPECIMEN D

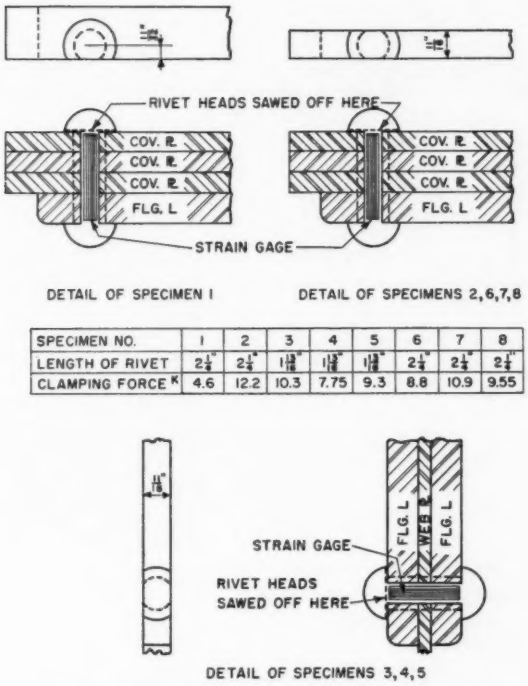
FIG. 3. DISTRIBUTION OF OBSERVED GAPS IN RIVETED SPECIMENS

The existence of gaps on both sides of the manufactured head and irregularly on one side of the rivet shank seemed to indicate that the shank had suffered primarily from bending during the driving process. The bending would be more apparent with longer rivets. The magnitude of the width of gaps observed in general was found to be far in excess of what could be expected from reduction of the area of the rivet when it cooled, after being driven hot. The latter fact suggested an incomplete filling of the rivet holes during the driving process.

The microscopic examination of the surface of some of the end rivets showed the mill scale intact, apparently indicating that the rivets had not been stressed beyond the elastic range.

In a more detailed examination of each rivet, the width of gaps between the rivet shank and the different plates forming the hole was measured by means of a feeler gage. In recording the gaps in each of the Specimens A, B, C, and D, their location was also recorded as "towards the end" or "towards the center," according to whether the gaps were towards the end support or the center line of the plate girder. However, these recordings could not be interpreted directly, and so a statistical system of comparison had to be adopted for the purpose. For comparison, the gaps observed in the plates and angles of each specimen were added separately. These totals, which were made for both the observations classified as "towards the center" and "towards the end" independently, are shown in Fig. 3, wherein they are distributed on either side of the horizontal line. A comparison of values of totals for Specimens A, B, and C with those of Specimen D suggests the following conclusions:

The distribution of gaps induced by manufacture is about equal towards the center as well as towards the end, as is observed in the case of Specimen D. Any slip in either direction will upset this balanced



SPECIMEN NO.	1	2	3	4	5	6	7	8
LENGTH OF RIVET	2½"	2½"	1 13/16"	1 13/16"	1 13/16"	2½"	2½"	2½"
CLAMPING FORCE K	4.6	12.2	10.3	7.75	9.3	8.8	10.9	9.55

FIG. 4. TESTS TO DETERMINE CLAMPING FORCE IN RIVETS (FIRST METHOD)

random distribution of the existing gaps by increasing their total on one side and reducing it on the other. This is revealed by the upset of the distribution pattern in Specimens A, B, and C as compared to the pattern of Specimen D. This upset in one direction or the other can be further complicated in that slip might occur not only during loading but also during unloading, and these two actions in opposite directions are of unknown magnitude. Since the test specimen was loaded and unloaded several times, both these factors need to be borne in mind.

If this analysis of the distribution of gaps is limited to the end two rows of rivets in the cover plates, and Specimens A, B, and C compared with D, the redistribution of gaps becomes more evident. This is shown on the right side of Fig. 3. The distribution clearly indicates the effect of slip, evidence indicating that the slip definitely affected the first two rows of rivets and might have extended over the portion of cover plates included in Specimens A and B. Specimen C shows a newly balanced distribution of the gaps, which may indicate that slip at the end of the third cover plate did not extend quite over the length of Specimen C. More definitely, the slip in cover plates 1 and 2 may have extended over the first five rows of rivets, but in cover plate 3 it may have extended over less than five rows.

The slip so suggested includes that which would result by overcoming the frictional resistance of the rivets and by readjustment of gaps during loading, and a part of it would be expected to manifest itself as "residual slip" upon unloading.

Estimation of Clamping Force

Tests were made with the aim of determining the clamping force produced in the shank of the rivet due to the shrinkage that results from the cooling of the hot-driven rivet. For this purpose 21 specimens of rivets were used. Two methods were used to determine clamping force, to enable a mutual checking of the results. In both methods the relaxation strains produced by release of clamping force were measured.

Method 1 (Strain-GageMethod). Saw cuts parallel to the center line of the rivet shank were made in such a manner as to graze the rivet shank and yield sufficient width for attaching a strain gage to the shank. The specimens prepared for the test are shown in Fig. 4. As will be noticed, two such cuts were made at opposite sides of the shank to produce a symmetrical state of stress, before and after the test. After the strain gage had been set in operation, the manufactured head of the rivet was removed by means of a deep saw cut, and the relaxation strains produced in the shank by the release of the clamping force were observed. (See Fig. 4.) In computing the stress, 30,000 ksi has been used as the modulus of elasticity. This stress times the actual area of the rivet in the test specimen gave the clamping force in the rivet. This value of the clamping force has been increased by the ratio of the whole rivet area to the rivet area in the test specimens.

Method 2 (Dial-Gage Method). The decrease in the length of the rivet shank was observed after the clamping force was released by removing the plates around the rivet (Fig. 5). From the grip length, the strain could be calculated, and from strain, the stress estimated.

In preparing the specimen for this test a small part of the top of the rivet head was ground flat, and two conical holes coincident with the center line of the shank were then drilled. To enable the removal of the plate, two deep saw cuts were made, running through the plates and just touching the shank of the rivet opposite a diameter of the rivet. The specimen so prepared was then set in a dial-gage arrangement as shown in Fig. 5 (a), and an initial reading was obtained on the 1/10,000 dial used. The plates around the rivets were then removed by repeated hydraulic jacking of a wedge in the groove formed by the saw cut. This is shown in Fig. 5 (b). The final reading of the reduced length was then taken as shown in Fig. 5 (c).

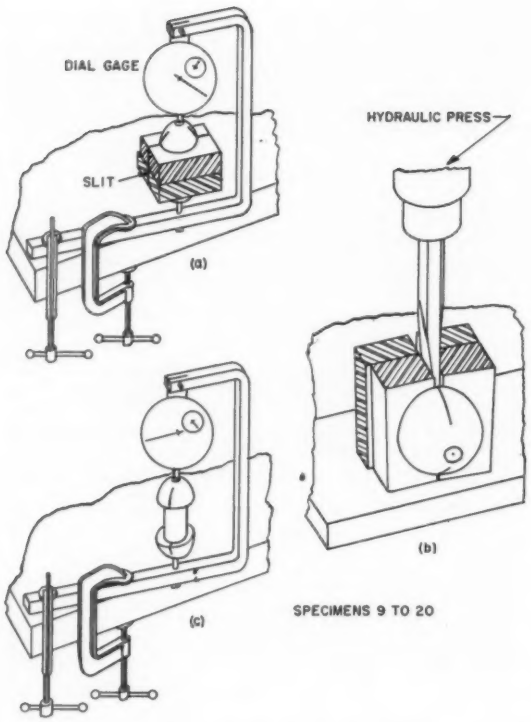


FIG. 5. TESTS TO DETERMINE CLAMPING FORCE IN RIVETS (SECOND METHOD)

The shrinkage in the length of shaft, produced by the removal of adjacent plates, was observed. The strain produced by the removal of clamping force was then estimated (on the assumption that the reduction of length took place) in the grip length of each of the rivets. Stress was computed by taking $E = 30{,}000$ ksi; the clamping force was estimated by multiplying this value by the actual area of the rivet.

Through these two methods, a uniform value of clamping force (10K) per rivet was obtained. By assuming a coefficient of friction between the plates, the value of the frictional resistance that could be made available through clamping force could be estimated.

These values cannot be regarded as the exact values of the clamping force. The forces in the rivets have undoubtedly been altered by removal of a rather small portion of the assembly. Cutting these pieces or extracting the plates probably further reduced the original clamping forces, and clearly the removal of a portion of the head of the rivet in preparing the specimens did so. The actual clamping forces must have been definitely higher than the ones observed. Nevertheless, these results prove the presence of a

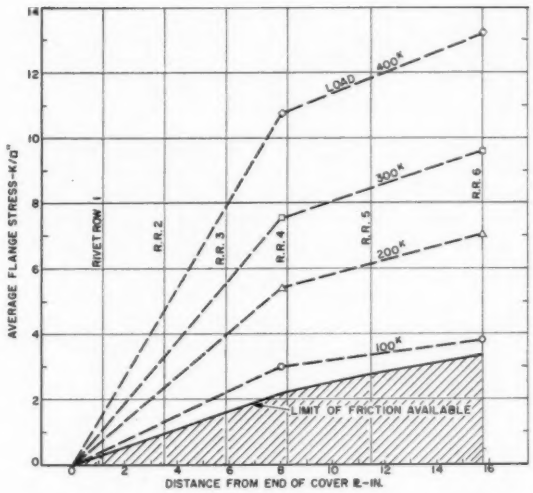


FIG. 6. STRESS DEVELOPMENT IN FIRST COVER PLATE

rather uniform and considerable clamping action of the rivets; thus the presence of a high frictional resistance against slip between the plates is to be expected.

From this data and from some information collected during the test (reference at the bottom of page 11) a reasonable idea can be formed of the mode in which the flange rivets act, both near the end of the cover plates and far from the end.

Action of a Long Riveted Joint in the Flanges

It was observed that the manner in which the stress was transferred by rivets near the ends of a cover plate and those towards the middle of the joint were substantially different. Though the rivets close to the end were in bearing and seemed to transfer more stress through bearing, those near the center of the joint were not in bearing and probably transferred all the shear through friction caused by the clamping force.

Action of Rivets far from the Ends of Cover Plates. Taking 0.4 as the coefficient of friction between the two plates and 10 kips as the clamping force available per rivet, and keeping in view that the maximum allowable spacing of 6 in. has been adopted, the shear resistance available is 1300 lb/lin in. This exceeds the maximum shear required to be resisted of 1270 lb/lin in. Since in most other cases the shear developed is less than the maximum taken into consideration and the spacing adopted is also closer, we can say the rivets acted as so many clamps, worked in friction at design load for the transfer of shear, and that at no stage is the static friction overcome.

(Continued on page 29)

The Analog and Digital Computer in Engineering Education

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P. L. Balise

Good common sense will always be an important ingredient of design, but, as engineering has progressed from an art to a science, empiricism has been superseded by analysis. This development is greatly accelerated by computers, which make it practical to use exact expressions whose evaluation was formerly too laborious. Recent engineering accomplishments are largely a result of this new ability to determine precisely the behavior of a system. Simplifying assumptions and empirical formulas are rapidly becoming obsolete, and progressive educators recognize the need for a corresponding revised approach in engineering courses.

In this new approach, the computer serves as a necessary tool. The question is not whether computers should be used in engineering education, but, rather, how they shall be incorporated into the curriculum. This is the subject of a Ford Foundation project at the University of Michigan, and it was a dominant question at the 1960 national meeting of the American Society for Engineering Education. Not only were several papers devoted to the subject, but it was also a frequent topic of conversation in the lounges.

It therefore seemed that readers of *Trend* might be interested in a report on the situation at the University of Washington. This article is not a technical discussion of computer programming, but an endeavor to present some experience that may be useful to those concerned with obtaining maximum educational values from computer facilities. Such values are difficult to measure: research is educational to the investigator aside from the new knowledge that may be uncovered.

Serving the entire University is the Research Computer Laboratory, equipped with an IBM 650 and an IBM 709. It is carrying on many active research programs, both contract and unsupported, and also serves as a laboratory for courses. In the College of Engineering there are an IBM 610 digital computer, an EASE analog computer, and a small Donner analog computer. They are particularly simple to become acquainted with, and so are well adapted to introduce digital and analog computation to students. This article will be primarily concerned with these machines.

Digital-Computer Applications

The IBM 610 is one of the smaller desk-type machines made by several manufacturers. It has an 80-word magnetic drum and punched tape for the storage of data, and is controlled by keyboard, punched tape, or wired panel. The simplicity of its keyboard commands and its automatic decimal point appeal to beginners. Although its small capacity limits its research usefulness, it has proved a very effective means of getting students to use a computer, after which they go on to program the larger machines. It is interesting to note that the small computer time has been almost equally divided among class work, thesis projects, and contract-type research. Some examples of its uses should be worth while.

Aeronautical-engineering students in a structures course are encouraged to use the digital computer to calculate equilibrium angles of attack for an aircraft at critical points on the load-factor diagram. Each student is given different parameters for a problem involving about twenty repeated computations, and the advantages and availability of the computer are pointed out by the professor, but with no coercion. About three-quarters of the class have elected the computer solution, using a program written by one student who spent about three hours learning computer operation from the student supervisor of the machine. Those who solved their problems by hand apparently felt that the one-third saving in time would not warrant dependence on the computer and the scheduling required for its use. With the new IBM 709 available in the Research Computer Laboratory, the professor is planning student projects for the writing of programs so that everyone can easily obtain rapid computer solutions and avoid lengthy routine computations in the course.

Although some chemical-engineering students use the IBM 610, most frequent use is made of the 650 for class demonstrations. These are given in courses

in thermodynamics, transport processes, and others at both the undergraduate and graduate level.

Upon its installation, the small digital computer was immediately adopted by civil engineers for some of their lengthy calculations. In sophomore surveying, it is used for inverse computation, the three-point problem, and traverse computations. A program was written for the simultaneous equations in adjustment of a level net by least squares; following demonstrations to the class, broken into small groups, each party runs its own figures through the program. Also using a previously prepared program, sophomores determine mass ordinates in cut-and-fill calculations with the IBM 650.

An example of the use of the small digital computer in electrical-engineering undergraduate courses is the determination of the transient in a circuit with a nonlinear inductor. The students calculate one point in the series expression by hand, thus being impressed with the labor involved. The computer solution is then demonstrated and compared with the curves obtained by assuming linearity and piecewise linearity. This procedure shows the value of the computer in making it practical to determine true behavior rather than resorting to poor approximations. In graduate classes the students readily do their own programming of straightforward problems after an hour's lecture and some outside study on the small computer. A typical example is the minimization of a closed-loop-system error as a function of several system parameters. Working individually or in small teams, the students get computer solutions. Here again the emphasis is on understanding the system behavior, the computer being used simply as a necessary tool to accomplish a mass of calculations. Both the IBM 610 and the 650 are used for illustration in digital-computer courses.

Mechanical-engineering undergraduates become familiar with the small digital computer in a machine-design course where it is applied to such problems as integration for a curved beam. Following a one-hour general demonstration, the students are all given the same problem, for which they must write the program, and invited to work singly or in groups. The computer instruction is treated like slide-rule training, as useful material that the student should want for his own benefit, but not as a formal part of the course. In spite of the opportunity to avoid learning much about the computer, about three quarters of the students are enthusiastic and go beyond the minimum requirements in computer familiarization.

Considerable use is made of the small digital computer in nuclear engineering, as in solution of the inhour equation, integration of fluxes by Simpson's rule, and solution of other reactor-hazards problems. The root-locus method of control theory is being applied in nuclear engineering, leading to computer solutions of polynomials in s.

Although this article is concerned primarily with class use of computers, a listing of some of the engineering research projects that have employed the IBM 650 may be of interest. These include wind-tunnel data reduction and vibrating-plate calculations in aeronautical engineering; diffusion-coefficient distribution for polymers in chemical engineering; class-average correlation in civil engineering; language translation, network power optimization, antenna evaluation, solution of electromagnetic diffraction problems, transient-response calculation, and computation of power spectral density of an ionospheric-fading function in electrical engineering; and determination of slot-jet mixing-velocity profiles and stress calculations in mechanical engineering.

Analog-Computer Applications

The EASE computer at the University of Washington has thirty amplifiers and associated nonlinear equipment such as multipliers and a diode function generator. It is the externally wired type, with resultant less accuracy and convenience for research problems, but with a patch-panel arrangement very easily understood by the beginner. Considerable modification has been made on the computer, and more is under way, including a supplementary panel for increased amplifier capacity, special-purpose nonlinear equipment, improved readout, and more versatile switch arrangement.

The digital computer is probably the more general research tool, but the analog computer seems more useful as a basic education aid. (Although one can argue relative merits, this seems inappropriate since analog and digital computers are essentially different, each with its own unique applications.)

The analog computer is particularly suited to demonstrating response of mechanical and electrical systems. Such demonstrations are given in a required sophomore course in mechanical engineering, with emphasis on the system behavior, both transient and steady-state. Instrumentation and control courses in mechanical engineering also employ analog-computer demonstrations. In a few minutes, principles are illustrated that would otherwise require hours of explanation. For most effective instruction, the panel is prepatched to allow quick changes in parameters and systems arrangements, anticipating student questions. The students are encouraged to suggest variations in the problem to investigate. Although the emphasis is on the system rather than the computer, the students are impressed with the computer's value as an analytical tool.

In electrical engineering at the University of Washington, the analog computer has been employed

mostly for research, particularly in servomechanisms. However, there is increasing interest in it for class use, as in a new guidance and control course whose laboratory periods will be devoted to analog-computer simulations.

The small Donner computer is used in nuclear engineering for laboratory classes and for research. For the latter purpose, more use of the EASE equipment is planned.

General Conclusions

Some general observations applicable to both digital and analog computers in engineering education may be interesting. It is most important that there be promotional effort to acquaint students and faculty with the computer facilities. Each of our computers stood relatively unused until actively publicized. This is only partly explained by computers being less common when we first obtained ours. Faculty and students are so busy that most of them will not notice a new facility unless it is brought directly to their attention, and there is also a tendency to fear and therefore to stay away from something unfamiliar.

This tendency is well illustrated by our experience with the small digital computer. For lack of space, it first shared a room with other uses, and no special educational program was conducted for it. When it was moved to a private room, lecture-demonstrations given to all interested students and faculty, and its use strongly encouraged, the situation changed from one in which the machine stood idle much of the day to its being used often, night and day. Similarly, the analog-computer use greatly increased when demonstrations and encouragement were provided.

A word of caution is in order regarding introductory computer lectures: they should be introductory. There is a tendency for the teacher to want to impress his audience with the machine's capability (and perhaps with his own knowledge). The average newcomer need not be convinced of what the machine can do; he probably already imagines it to be a most potent electronic brain. He does need to be convinced of his own ability to handle the computer. For this purpose, it is best to ignore the more sophisticated aspects and illustrate with a simple problem that a beginner can follow completely even if the problem would not normally require computer solution. The object is to get the student to use the computer; once he does, he will learn for himself its many valuable features.

A particularly worthwhile arrangement is the provision of an Experiment Station assistant to supervise the digital-computer facility. Three men have held this position so far, none of whom had any prior computer experience. All soon became adept with the machine and enthusiastically helped others. The presence of a friendly expert who can quickly untangle a difficulty is important in preventing discouragement among new users. With both analog and digital computers, beginners frequently encounter baffling situations that an expert can resolve in a moment.

The question of one large computer vs. several small ones is not easily decided. The small digital computer can do many of the problems that are assigned to big machines, but requires an impractically long time. However, for small problems the small computer can be more efficient, since although the large computer would operate faster, the total man hours may be greater, including programming and scheduling computer time. Professors who become proficient with the small machine use it effectively for determining a few dozen points, in considerably less time than by slide rule or desk calculator. For such problems, as well as for introducing students to digital computation, it is valuable to have a small computer readily available on a somewhat informal basis, and to get the faculty familiar with its operation.

The small analog computer usually cannot substitute for the large computer to solve complex problems. The advantage of having several desk-top analog computers is that they permit several students to work simultaneously, but their capacity is so limited that they cannot accommodate the majority of typical problems, and so are useful primarily to teach analog-computer technique. If the emphasis is on analyses rather than on computer technique, perhaps the better plan is to concentrate on a single versatile machine, maybe one with sections that may be combined or operated independently. Several small computers have considerable educational value, but probably they should not be purchased at the sacrifice of nonlinear capacity in a larger machine.

In conclusion, this educational value as it relates to problem analysis should be noted. To program either a digital or analog computer demands an unambiguous statement of the problem. The clear understanding thus required is one of the greatest benefits of computers in engineering education.

FIFTH WORLD FORESTRY CONGRESS

Seventy-one nations participated in the Fifth World Forestry Congress held on the UW campus from August 29 through September 10. Two thousand delegates attended the conference, where over 200 papers were presented in the key languages, English, Spanish, and French. The central theme of the conference was multiple use of forests.

A Study of the Post-Weld Thermal Treatment of an Aluminum-Copper Alloy

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Aluminum alloys in which copper is the primary alloying element have been the subject of considerable practical and theoretical investigation since the discovery of their capacity to develop important property changes during the process of aging after a solution heat treatment. Most of these investigations have been concerned with studies of formed products, the processing and eventual heat treatment of which has provided comparatively homogeneous structures. An important fabricating technique that results in a somewhat inhomogeneous structure is welding. The inhomogeneity arises from the fact that the weld metal is basically a cast structure and for most alloys this implies chemical heterogeneity on a microscale. The weld differs from a normal cast structure, however, in that it is subjected to a much different set of conditions of constraint upon solidification and cooling than is a conventional casting.

As a result of these circumstances, a metal with a large solidification shrinkage and a large thermal coefficient of expansion (or contraction) is subjected to strain conditions of such magnitude across the weld-base metal interface that elastic deformation and even plastic deformation and localized rupture can occur. Consequently, stress heterogeneity enters the picture in a very significant manner. Furthermore, it is well to consider that the ultimate objective in welding is to obtain a joint having mechanical and chemical properties equal to or approaching those of the base metal. This aim can be accomplished only by providing a weld-metal structure with mechanical and chemical properties equivalent to, or at least closely approaching, those of the base metal.

Aluminum-copper alloys undergo a large solidification shrinkage (as great as 5/32 in. per linear foot) and have a large coefficient of thermal expansion (25 x 10^{-6} in. per inch per degree centigrade). These two factors contributed to the difficulty initially encountered in fusion welding these alloys, in that they were so susceptible to so-called "hot cracking" that they were considered non-weldable. It was found, however, that the hot cracking problem could be avoided, providing the rate of heating during welding was held to a minimum. This is most readily accomplished by utilizing the Tungsten Electrode-Inert Gas welding process (commonly called the TIG process) in combination with careful control of important welding variables. Among the latter are voltage, current, weld-wire feed, and electrode travel rate. With proper control equipment, weldments can be produced in aluminum-copper alloys that exhibit joint efficiencies of 100%.

Providing a satisfactory joint in such alloys answers only a portion of the practical problem. To attain the equally important objective of providing a mechanical and chemically desirable weld structure, post-weld thermal treatments are required. If the weldment is not subjected to such thermal treatment, there is no object in welding the high-strength, heat-treatable alloys since the as-welded strength is considerably below that of many non-heat treatable alloys. The present preliminary investigation is pointed to this important area of post-weld thermal treatment. The subject of the study can no longer be bypassed if high-strength aluminum-alloy welded parts are to be dependably produced.

Experimental Procedure

Materials. The aluminum-copper alloy 2014 was selected for this study. This alloy has been in production for many years and its properties and physical behavior in the formed and heat-treated condition are rather well understood. In line with conventional practice both the plate to be welded and the weld wire were of the same nominal composition. The plate dimensions were 0.250 in. x 5 in. x 20 in. The weld wire was .062 in. in diameter.

Equipment. Welding was done with a Linde electronically controlled welding machine with a Vickers full-wave rectified d-c power supply. All heat treating was done in circulating atmosphere furnaces. Standard quenching, hardness, tensile testing, hydraulic bending, and metallographic preparation and examination facilities were used.

Preparation of Specimens. The alloy plates were degreased in methyl-ethyl ketone and cleaned by wire brushing. Square butt welds were made along the 20-in. dimension of the plates under the following welding conditions:

11 volts, 250 amperes
(Tungsten electrode negative),
40 in. of wire per minute,
7 in. of torch travel per minute, and
125 cu ft per hour of helium cover gas.

TABLE I

PHYSICAL PROPERTIES OF WELDMENTS

PROPERTY	HEAT TREATMENT		
	None (as welded)	SHT + Natural Aging	SHT + Artificial Aging
Ultimate strength, psi	26,600	62,200	68,500
Yield strength, psi	11,700	38,000	63,500
Hardness, weld zone, R_B	51	73	86
Hardness, base metal, R_B	8	74	84
Bend angle, 5T radius	22°	180°	15°
Fracture location	Weld	None	Weld

Following the completion of the welding operation, all weldments were checked by x-ray radiography to assure freedom from internal defects. Standard tensile specimens, 10 in. long, were machined from the weldments with the weld zone transverse to the specimen axis. Top and bottom weld beads were then machined flush with the surface of the specimen. These specimens were used both as tensile coupons and as bend-test specimens.

To check on the heat-up rate, thermocouples were placed in the center of three test samples and the temperature change measured during the welding operation. The rate was found to be 175° to 200° F per hour.

Evaluation of Physical Properties. The ultimate tensile strength and 0.2% offset yield strength were determined by pulling specimens in a standard Tinius Olsen tensile testing machine. Rockwell B (100 kg load, 1/16 diameter ball) hardness measurements were made on both the base metal and weld metal on portions of the weldments not used in tensile specimen preparation. Weld zone ductility was determined by hydraulically bending a standard specimen around a 5-T radius (T is the specimen thickness). The value used was the angle at which fracture became macroscopically apparent.

Preliminary Tests. A series of preliminary tests were run to determine the magnitude of the effects of standard heat-treatment procedures. Three separate conditions of the weldment were chosen as follows:

1. As-welded condition (these specimens were allowed to stand at room temperature one week after welding and prior to testing).
2. Solution-heat-treated and naturally aged condition. (These specimens were solution heat treated for one hour at 935° F, quenched within 10 sec in water at 150° F, and then allowed to stand at room temperature 48 hours prior to testing.)
3. Solution-heat-treated and artificially aged condition, (solution heat treated and quenched as in 2, then artificially aged by isothermal heating for 8 hours at 350° F).

The average physical properties shown by specimens in these three conditions is given in Table I. All values are based on four tests per condition.

Further Studies. Because of the wide range in important properties obtained in the preliminary tests, it seemed advisable to examine the effects of heat treatment in considerably more detail. To this end a more extensive series of tests were run. This series had two major objectives: (1) to determine the effect of time of solution treatment and (2) to determine the effect of time of artificial aging. For the first portion of this work the standard aging treatment of 350° F was used. In the second part, an aging temperature of 300° F was selected on the

TABLE II

EFFECT OF SOLUTION HEAT TREATMENT AND ARTIFICIAL AGING TIME ON THE PHYSICAL PROPERTIES OF WELDMENTS

Solution Heat Treatment (deg F)	Aging Treatment (deg F)	Ultimate Tensile Strength (psi)	Yield Strength (psi)	Bend Angle 5-T Radius (deg)	Rockwell B Hardness	
					Base Metal	Weld
1 hr at 935	48 hr at 70	61,000	38,300	180	75	76
1 hr at 935	8 hr at 350	70,000	62,200	10	81	82
24 hr at 935	8 hr at 350	71,200	61,400	9	82	80
48 hr at 935	8 hr at 350	70,500	63,000	12	81	83
96 hr at 935	8 hr at 350	70,300	58,000	15	82	78
1 hr at 935	1 hr at 300	62,300	35,100	180	74	72
1 hr at 935	2 hr at 300	63,100	33,200	180	70	74
1 hr at 935	4 hr at 300	58,400	30,100	180	71	76
1 hr at 935	8 hr at 300	65,200	45,300	180	74	79
1 hr at 935	12 hr at 300	68,300	58,100	20	77	81
1 hr at 935	16 hr at 300	71,600	62,300	15	83	76
1 hr at 935	24 hr at 300	58,600	32,400	20	79	60

basis of earlier work, which showed that critical changes in properties are more easily detectable with a lower aging temperature.

Furthermore, a check was made of the effect of the temperature of the quenching water. When essentially the same results were obtained on specimens quenched in water at room temperature as at 150° F and naturally aged (compare data in Tables I and II), it was decided that the more convenient room-temperature quench would be used. All specimens were quenched within 10 sec.

The various heat treatments and resulting physical property values are given in Table II. As in Table I each is the average of four tests per condition.

Discussion

A number of interesting features shown in the experimental data have both practical and fundamental metallurgical interest. The outstanding difference in the preliminary tests occurs between the naturally and artificially aged specimens, where the ductility is reduced to a very low figure by the latter treatment. This is likewise accompanied by a large increase in yield strength and a significant hardness increase. The tensile data on the as-welded specimen, which are about what one would expect, point up the physical-property advantage to be gained by heat treatment. The low bend ductility value also might be predicted from the microstructure, which shows almost continuous channels of brittle interdentritic material along which cracks can easily be propagated (Figs. 1 and 2).

With solution heat treatment and quenching, one observes a marked reduction in the interdendritic filling (due to absorption) and the removal of the coring. Most importantly, the extensive channels are broken up and the matrix is more continuous (Figs. 3 and 4).

A very interesting microstructure accompanies natural aging (Fig. 5). Here an unusual case of annealing twins in an aluminum alloy is shown, apparently a result of the intense residual stresses existing in the metal after the quenching operation. The twin boundaries and the grain boundaries are comparatively free of the excess constituent, and the matrix material remains continuous.

With artificial aging, one observes two interesting effects (Fig. 6). One is the reduction in the amount of twinning, probably owing to the stress relief occurring rapidly at the artificial aging temperature. Secondly, and more importantly, the structure shows a reversion to a state somewhat resembling the as-welded condition, but differing from it in that a reverse coring has now occurred. The copper atoms, which are responsible for the color change, have preferentially diffused, either to form larger quantities of the Cu Al_2 intermetallic phase at the grain boundaries or into the original dendrites. The important effects here are two. The first is that the larger quantity of copper-rich intermetallic phase provides a more continuous intergranular brittle substance, and the second is that the formation of Cu Al_2 has robbed the surrounding environment of copper atoms, leaving zones (light etching structure in Fig. 6) of copper-poor structure. Apparently the expected high ductility of these depleted zones is more than overcome by the presence of the brittle component, and thus low overall ductility results.

In the more detailed study, the first point of importance is that the physical-property values are influenced little by extended solution heating times up to 96 hours, and apparently chemical homogenization is reached after one hour at 935° F. On the other hand, aging time after the solution heat treatment and quenching is of critical importance, particularly in its effect on ductility. The data show that at between eight and twelve hours at 300° F a structural condition is reached wherein the bend ductility is reduced to dangerously low values. Quite significant changes occur in the tensile values, particularly in the yield strength, with increasing aging times at 300° F.

It should be pointed out that the actual values of the bend angle are of relatively minor significance. In those tests where 180° bends were not obtained, the bend-angle scatter ranged from 5 to 28°. Apparently welds are ductile (show 180° bend angles) or are brittle (show less than 30° bend angles) depending on the aging treatment, in which both time and temperature of aging are significant. Specimens showing the brittle behavior failed rapidly by transverse fracture through the weld zone with all cracks being initiated at an angle of 45° to the direction of applied load.

Another point of considerable significance is that neither hardness nor yield-strength values provide a dependable measure of the ductility in welded structures. Though one might expect that increasing values of both tensile and yield strengths would be accompanied by reduced ductility, as is generally shown by the data, the figures for 24 hours at 300° F show the reverse effect.

Conclusions

In aluminum-copper alloys, post-weld thermal treatments must be carefully planned as to time and temperature of aging in order to avoid the formation of critical concentrations of brittle components along specific structural regions. The inherent brittleness of the intermetallic phase is only a factor in the problem. Its development in an alloy structure is accom-

(Continued on page 30)

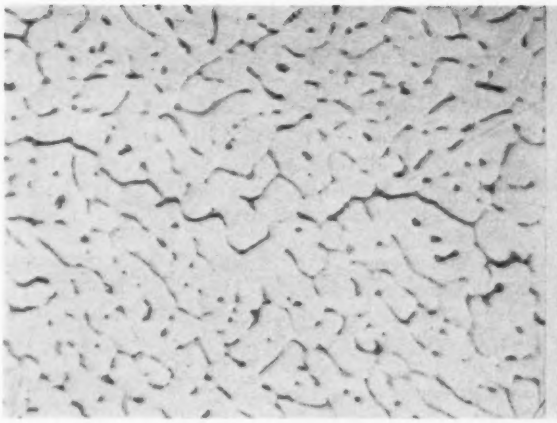

FIG. 1. AS-WELDED CONDITION; UNETCHED

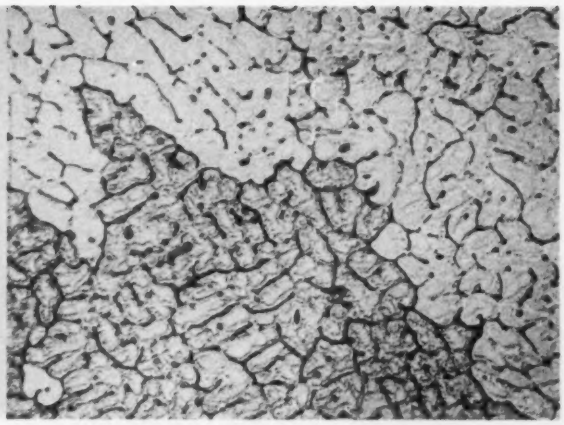

FIG. 2. AS-WELDED CONDITION; 10-SEC KELLERS ETCH

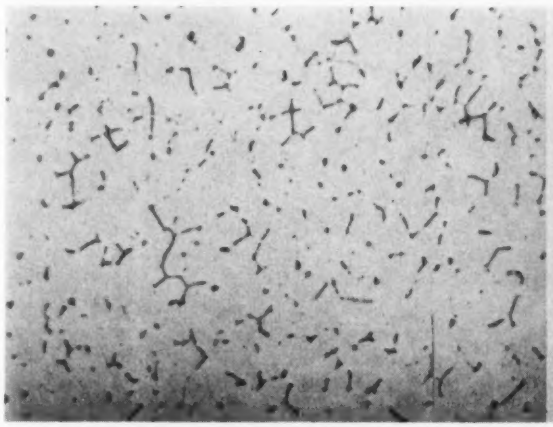

FIG. 3. POST-WELD HEAT TREATED 1 HR AT 935°F; UNETCHED

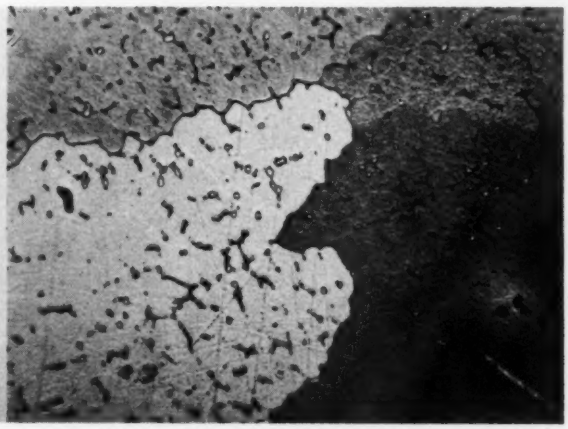

FIG. 4. POST-WELD HEAT TREATED 1 HR AT 935°F; AS-QUENCHED CONDITION; 10-SEC KELLERS ETCH

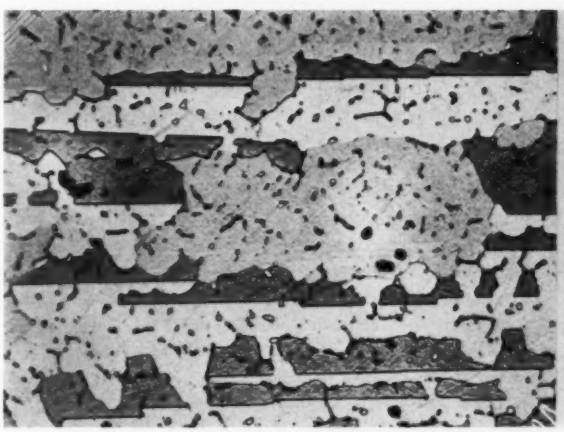

FIG. 5. POST-WELD HEAT TREATED 1 HR AT 935°F; NATURALLY AGED 48 HR;10-SEC KELLERS ETCH

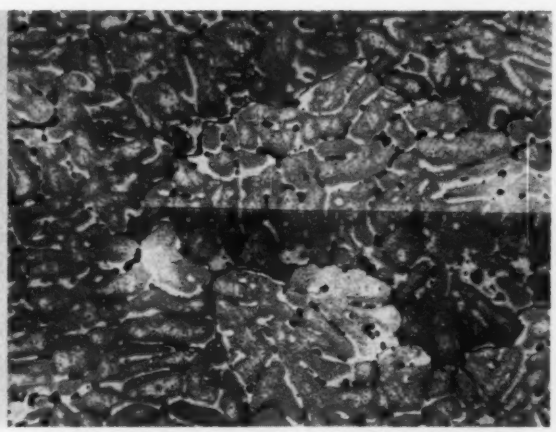

FIG. 6. POST-WELD HEAT TREATED 1 HR AT 935°F; ARTIFICIALLY AGED 8 HR AT 350°F; 10-SEC KELLERS ETCH

SPECIMENS SHOWING WELD ZONES IN 2014 ALUMINUM TIG WELDS (500X)

Two-Dimensional Turbulent Mixing Between a Free Stream and a Confined Parallel Slot Jet

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The problem of turbulent mixing between two parallel streams has been studied both theoretically and experimentally by many investigators[1,2,3,4,5,6] during the past three decades. A great deal of the past work has dealt with mixing between completely unconfined, or free, jets. More recently the problem of turbulent mixing in the presence of a solid boundary has been given considerable attention.[7,8,9]

This problem is important because flow patterns of this type may be used in the cooling of surfaces that might otherwise be heated excessively by high-temperature external streams. For example, in the combustion chambers of gas turbines relatively cool air may be injected from circumferential slots between the hot combustion gases and the liner to keep the liner cool. Another example is the use of tangential injection of a cool fluid along the surfaces of a hypersonic vehicle to counteract aerodynamic heating effects.

A method of obtaining theoretical solutions that would allow one to predict the flow field downstream of the slot-jet exit in problems of the type just mentioned would be useful. To date, a satisfactory method of solution has not been found. In fact, even the comparatively simpler case of turbulent, incompressible, constant-pressure mixing of two streams of the same gas at the same temperature bounded on one side by a solid wall has not been solved sufficiently to allow velocity profiles downstream of the jet exit to be predicted. This paper reports briefly on the results of an investigation of this case.

Theoretical Considerations

The flow pattern under consideration is shown in Fig. 1. As shown, it consists of several distinct regions: a boundary-layer region adjacent to the solid wall; an isentropic core of the slot jet; a free-mixing region between the slot jet and the external stream; the external stream; and then, downstream of the point where the boundary layer and the mixing region meet, a region in which the flow proceeds toward an ordinary boundary-layer type of flow. Thus a solution to the problem would require consideration of boundary-layer flow, free mixing, and a combination of the two.

M. E. Childs

Because flows involving the mixing of streams have a boundary-layer nature, the ordinary boundary-layer equations may be applied to them. For incompressible, constant-pressure, two-dimensional flow with a steady main component of flow in the x-direction, the differential equations for the boundary layer are: the momentum equation,

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{\rho}\frac{\partial \tau}{\partial y} \qquad (1)$$

and the continuity equation,

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0. \qquad (2)$$

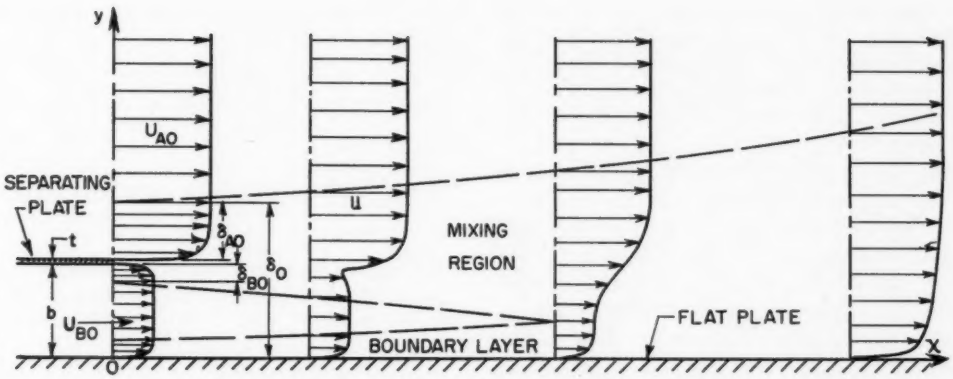
in which u and v are the time-average components of velocity in the x and y directions, ρ is the density, and τ is the shear stress. For laminar flow the shear stress may be expressed in terms of the dynamic viscosity, μ, which is a function of temperature only over a wide range of pressures. Rouleau and Osterle[7] have solved the problem of isothermal laminar mixing in the presence of a solid boundary by writing the momentum and continuity equations in finite-difference form and solving them by an iterative procedure.

For turbulent flow the shear stress may be expressed in terms of time-average values of the properties or their products, as

$$\tau=\left(\mu\frac{\partial u}{\partial y}-\rho\,\overline{u'v'}\right)$$

in which u' is the velocity-fluctuation component in

* Mr. Ip is now employed as an associate research engineer by the Boeing Airplane Company. This article is based upon the thesis written for his M.S. degree in Mechanical Engineering, which he received in June, 1960.



F.G. 1. JET MIXING BETWEEN A SLOT JET FLOWING ALONG A FLAT PLATE AND AN ADJACENT PARALLEL STREAM

the x direction and v' is that in the y direction. The turbulent-flow problem is obviously more difficult to handle since the shear stress, even in isothermal flow, is a function of the flow field. For mixing in the presence of a wall, the problem is further complicated by the fact that very near the wall the first component of the shear-stress term dominates, while at a short distance away from the wall and beyond the second component dominates. In fact, in free mixing only the second component is included in the momentum equation, and the shear stress usually is written as

$$\tau = \rho \epsilon \frac{\partial u}{\partial y}.$$

where ρ is the fluid density and ϵ is the eddy or apparent kinematic viscosity. By using this new expression for τ, Eq. (1) becomes

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\partial}{\partial y}\left(\epsilon\frac{\partial u}{\partial y}\right). \qquad (3)$$

If there were available a suitable means of representing ϵ in terms of other variables, the method employed by Rouleau and Osterle might be used to solve Eq. (2) and (3) for the velocity distribution. No really suitable expression for ϵ has been devised, so investigators have been forced to make various simplifying assumptions and approximations in their attempts to get theoretical solutions to turbulent-flow problems. For instance, in free-mixing problems the assumption is often made that ϵ is a function of x only. This helps the situation, but the manner of variation of ϵ with x still must be known in order to obtain a solution.

For mixing of jets without initial boundary layers, success has been attained by assuming that ϵ is proportional to the width of the mixing region, which in turn is assumed to vary linearly with x. For mixing of jets with initial boundary layers, such a simple expression is not satisfactory except at great distances from the jet exit where the effects of the initial boundary layer have decayed. Thus another means of treating flows with initial boundary layers or flows in the presence of a solid wall is necessary.

In investigations of free mixing with initial boundary layers conducted at the University of Illinois[6,10,11] considerable success was attained in correlating theoretical and experimental velocity profiles by working with a drastically simplified momentum equation that did not involve the y component of velocity v. This equation was solved for u without regard for satisfying the continuity condition. In the work at Illinois ϵ was first assumed to vary with x only. The momentum equation was then linearized by means of the small-perturbations method, in which it was assumed that the velocity component u could be written in terms of a fixed reference velocity, U_o, and a perturbation velocity u_1 as

$$u = U_o + u_1$$

with

$$u_1 << U_o \text{ and } v \approx u_1.$$

When these relationships were substituted into the momentum equation and higher-order terms neglected, the following equation resulted:

$$U_o\frac{\partial u}{\partial x} = \frac{\partial^2 u}{\partial y^2}. \qquad (5)$$

By use of an integral transformation with ϵ as its kernel function, Eq. (5) was then transformed into the form of the one-dimensional heat-conduction equation from which downstream velocity profiles could be calculated in a transformed x-y-coordinate system for a given initial velocity distribution at the

jet exit. This transformation, which will be shown later, eliminated ϵ from the momentum equation without requiring any assumptions regarding its form; in fact, correlation of the theoretical profiles thus obtained with the experimental profiles allowed the form of ϵ to be determined.

One might hope that the simplifications used in the work at Illinois could be applied successfully to the case of turbulent mixing in the presence of a wall since the flow patterns would be similar except in the vicinity of the wall. Accordingly, a procedure similar to that used at Illinois was tried in the present investigation, the only difference being in the form of the momentum equation used to calculate u. If Eq. (4) is compared with Eq. (5), it is seen that the use of the small perturbations method amounts to neglecting the term $v\ \partial u/\partial y$ in the momentum equation as well as the variation of u in its position as coefficient of $\partial u/\partial x$. Physical considerations indicate that it might be more reasonable to assume merely that the second term in Eq. (4) is negligible and retain the coefficient, u, of the first term as a variable. If this is done ϵ may still be transformed out of the equation. The resulting equation then may be written in finite-difference form and solved by iteration for u. Use of the above assumption implies that $v\ \partial u/\partial x$ is much smaller than $u\ \partial u/\partial x$. This should be approximately true except for the region immediately behind a separating plate or in the immediate neighborhood of a wall where v is comparable in magnitude to u and where $\partial u/\partial y$ is of considerable magnitude. In these regions errors due to the assumption could be large.

With the above assumption, the equation of motion becomes

$$u\frac{\partial u}{\partial x} = \epsilon\frac{\partial^2 u}{\partial y^2}. \tag{6}$$

If one now introduces the dimensionless variables

$$\phi = \frac{u}{U_{Ao}},\quad \psi = \frac{x}{\delta o},\quad \zeta = \frac{y}{\delta o},$$

in which U_{Ao} is the free-stream velocity of the external stream and δo is a characteristic length of the flow—in this case assumed to be the width of the slot jet plus the boundary-layer thickness in the external stream—, he obtains

$$\phi\frac{\partial\phi}{\partial\psi} = \frac{\epsilon}{U_{Ao}\delta_o}\frac{\partial^2\phi}{\partial\zeta^2}. \tag{7}$$

At this point ϵ still appears in the equation. However, introducing the new variable ξ defined by the integral transformation

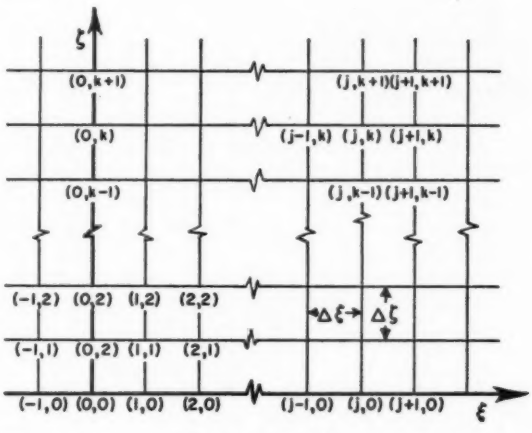
$$\xi = \frac{1}{U_{Ao}\delta o}\int^{\psi}\epsilon d\psi \tag{8}$$

Eq. (7) becomes

$$\phi\frac{\partial\phi}{\partial\xi} = \frac{\partial^2\phi}{\partial\zeta^2}. \tag{9}$$

This equation, which no longer contains ϵ, may now be written in finite-difference form and solved for ϕ by the iterative procedure used by Rouleau and Osterle in their work on laminar mixing.

Consider the rectangular mesh in the transformed ξ, ζ-coordinate system shown in the accompanying sketch:



The subscript pair (j,k) is used to denote the mesh point in the jth column and the kth row. The partial derivatives in Eq. (9) may be approximated by the difference quotients as follows:

$$\frac{\partial\phi}{\partial\xi} = \frac{\phi_{j+1,k}-\phi_{j,k}}{\Delta\xi}$$

$$\frac{\partial^2\phi}{\partial\zeta^2} = \frac{\phi_{j+1,k+1}-2\phi_{j+1,k}+\phi_{j+1,k-1}}{(\Delta\zeta^2)}.$$

Substituting these relationships into Eq. (9) one obtains

$$\phi_{j,k}\frac{(\phi_{j+1,k}-\phi_{j,k})}{\Delta\xi} = \frac{\phi_{j+1,k+1}-2\phi_{j+,k}+\phi_{j+1,k-1}}{(\Delta\zeta^2)}. \tag{10}$$

In Eq. (10) there are three unknowns, $\phi_{j+1,\,k}$; $\phi_{j+1,\,k+1}$; and $\phi_{j+1,\,k-1}$. If a sufficient number of points, N, is taken in the column j so that the uppermost point $(J+1, N+1)$ in column j + 1 lies essentially in the external free system, then the points $\phi_{j+1,0} = 0$ and $\phi_{j+1,\,N+1} = 1$ are known, leaving N simultaneous

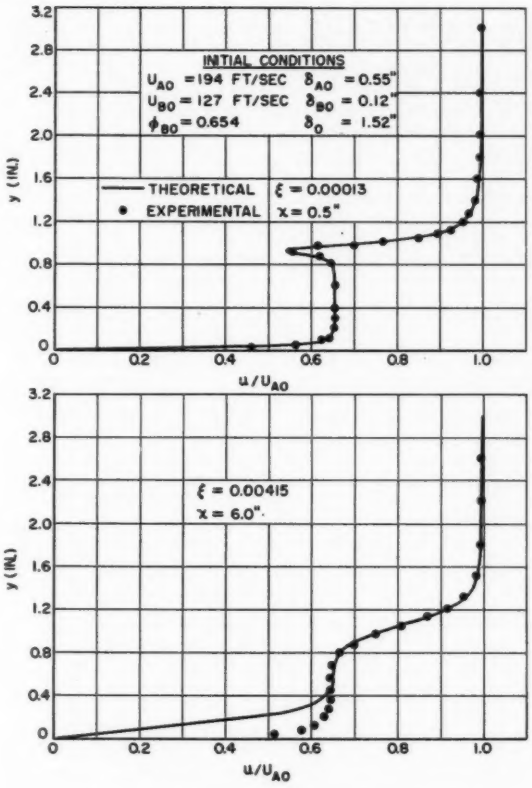


FIG. 2. COMPARISON OF EXPERIMENTAL AND THEORETICAL VELOCITY PROFILES (TEST SERIES I)

equations with N unknowns, $\phi_{j+1,k}$, which may be solved either by relaxation or iteration. Once ϕ is determined as a function of ζ at ξ corresponding to $j + 1$, ϕ may then be determined at the next downstream value of ξ corresponding to $j + 2$, etc. In this investigation the iteration procedure was used to obtain solutions.

Typical theoretical profiles resulting from a given set of initial conditions are shown for two downstream positions in Fig. 2. These profiles will be discussed along with some experimental profiles in a later section on results of the investigation.

The Experimental Program

The experimental apparatus used in this investigation was designed to produce a flow pattern such as that shown in Fig. 1, with air as the medium. Figure 3 shows the plan and front views of the plenum, exhaust nozzle, flat plate, and necessary duct arrangement used to produce this pattern. Air was supplied by means of a centrifugal blower driven by 30 hp a-c motor. The plenum, which was constructed of ¾-in.

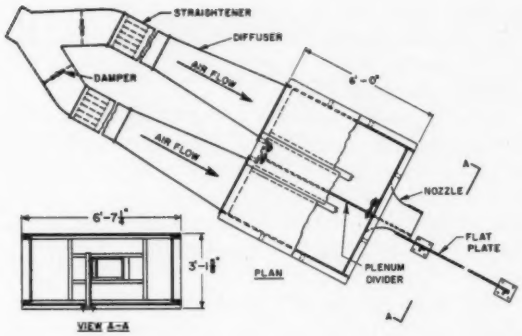


FIG. 3. DIVIDED PLENUM, AIR DUCTS, AND TEST SECTION

plywood and the necessary framing, was divided into two separate chambers by means of a wooden divider plate. A stainless-steel sheet, 0.036 in. thick, attached as an extension to the wooden divider plate, was used to separate the streams in the exhaust nozzle.

The top and bottom plates of the exhaust nozzle were made of ¾-in. plywood with a hardboard facing. The sides of the nozzle and the flat plate along which the slot jet flowed were made of galvanized sheet metal. Plywood backing was used to keep the flat plate rigid. The nozzle height was 10 in.; the nozzle width, including the slot, was 14 in. The plenum divider plate and the attached stainless-steel separator plate could be moved to allow for various slot widths. Velocities of the slot jet and external jet could be varied by adjusting the dampers in the ducts upstream of the plenum chambers.

Experimental data were obtained for four sets of initial flow conditions. In all four tests a slot width of 0.93 in. was used. Air velocities were determined by means of dynamic head probes that could be positioned by a suitable traversing mechanism. To establish the initial conditions for each test, detailed dynamic head readings were taken at the nozzle exit ($x = 0$) in a horizontal plane approximately halfway between the top and bottom plates of the nozzle. Velocity profiles in the mixing region were also measured in the horizontal midplane. Profiles were determined at $x = 0.5$, 1, 2, 4, 6, 10, 15, 20, and 30 in. downstream from the nozzle-exit plane.

Results of the Investigation

Typical results of the investigation are shown in Fig. 2. The flow conditions for the test giving these results are listed on the figure. The boundary-layer thicknesses listed are distances from the separating plate at which the velocities were equal to 0.99 of the free-stream values. The theoretical profiles, which were calculated as a function of ζ for various values of ξ, are shown as a function of y. The correspond-

ing values of ξ are listed on the figure. These values of ξ were determined by finding the theoretical profile that agreed best with the experimental profile for the particular value of x.

As is apparent from the figure, good correlation was obtained between the theoretical and experimental profiles at $x = 0.5$ in. This would be expected since the cross-section under consideration is only a short distance downstream from the nozzle-exit plane, where the theoretical and experimental profiles are identical.

At $x = 6$ in. agreement was good in the free-mixing region. Near the wall, however, agreement was so poor that theoretical profiles were not calculated for values of ξ corresponding to positions further downstream. In the one other test for which theoretical profiles were calculated, comparable results were obtained.

Even though the results obtained were not completely satisfactory, the fact that the drastically simplified form of the momentum equation appears to be suitable for calculating velocity profiles in the free-mixing region is encouraging. Apparently, mixing occurs rapidly enough downstream of the separating plate that the conditions assumed in obtaining the simplified momentum equation are approached quickly. It should be possible, by determining velocity profiles for various initial flow conditions and comparing them with theoretical profiles, to find a relationship between ξ and x that would allow mixing profiles in this region to be predicted.

For flow near the wall, it may be possible to establish empirical relationships that will allow boundary-layer profiles to be predicted. Such relationships, used in combination with the simplified theory for the free-mixing region, might then allow the entire profile to be predicted for given initial conditions as far downstream as the point where the boundary layer and free mixing region meet. Methods of treating the problem in this manner are being investigated.

For profiles farther downstream, correlations, empirical or otherwise, have not yet been made. Efforts to treat the flow in this region are also being continued.

ACKNOWLEDGMENTS

The experimental phase of this investigation was conducted on equipment built for a National Science Foundation project on jet mixing. The theoretical calculations were made on the IBM 650 computer in the University of Washington Research Computer Laboratory. The computer time for the calculations was granted by the Committee on Unsupported Research.

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A Glimpse of the Future?

The medical student who intended to be a nose specialist, specializing on the right nostril, may be an extreme example of present trends. One would not expect to find in engineering practice such fine distinctions as the medicos indulge in.

These thoughts are engendered by a paper on heat furnaces recently given at an S.A.E. meeting, in which the requirements of a furnace design are discussed. The author states: "In order to establish a furnace design the services of the metallurgist are needed to set the time and temperature uniformity specifications. In turn, the services of an aerodynamist are needed to analyze and predict the flow of the wind. The services of the heat transfer specialist are needed to calculate how rapidly and how uniformly the load can be heated. The structural designer is needed for both designing the fan and the duct systems, and also the furnace enclosure. An engineer who specializes in mechanical handling should also be consulted on the best means of bringing the work to the furnaces, moving it through the furnace, and then taking it away from the furnace. And, of course, governing all of these analyses is the primary objective of all engineering: Economics."

The furnace in this instance is a carburizing apparatus, in which both heat and carbon are transferred. Its complications are apt to surprise those unfamiliar with the process. From *Engineering Digest*, Vol. 6, No. 8, Aug., 1960.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

BUSH, L. F., "A Study of the Fatigue of Thin Plates," M. S. in Civil Engineering, 1960.

A square pin-connected loading frame was found to be suitable for the study of fatigue on thin plates. Such a frame, when loaded in tension along one diagonal, applies pure shear to a plate specimen mounted in the frame.

Tests on specimens of square steel plate with a clear depth-to-plate thickness ratio of 416 showed that the typical fatigue crack propagated along the axis of the plate buckle, with occasional branching of these cracks at approximately 90 deg to the main crack. Crack propagation did not have noticeable plastic action at the tip of the crack. These occurrences give the crack the appearance of a brittle fracture, although the rate of crack propagation is very slow. The cracks probably originated on the concave side of the buckle. Buckling of these specimens was so extensive that the bending stresses from buckling far exceeded the membrane stresses produced by the action of the loading frame. Further research is recommended to determine the effects of other depth-to-thickness ratios, reversing loads, and various degrees of edge restraint.

WHEELER, P. C., "Application of the Truncated Integral-Squared Error in a Performance-Measuring Adaptive Control System," M. S. in Electrical Engineering, 1960.

The research concerned the applicability of an approximation to the integral-squared error to a two-variable performance-measuring adaptive control system. The total system investigated includes a plant whose parameters are a function of the environment in which the system is operating, a model whose response to a previously specified test-input signal represents the optimum plant output, a controller whose parameters may be adjusted to alter the plant output, and an adaptive computer used to determine the best values for the controller parameters by a series of iterative adjustments. Minimum integral-square error (I.S.E.) defines the best controller parameter values.

The basic problem investigated is whether minimizing the approximation to the I.S.E. by a previously tested procedure will result in a "suitable adjustment" of the controller parameters. For this research such a "suitable adjustment" is defined as one that reduces the I.S.E. to $0.01N^2$ or less when the common system and model input is a step of amplitude N. The approximation to the integral-square error investigated here is the truncated I.S.E. (I_T); it results from integrating over a finite time T (the truncation time) to approximate the infinite integral associated with I.S.E.

Of the seven adaptation attempts performed during the course of this research, six resulted in suitable adjustment of the controller. The remaining test run was also successful, even though a "suitable adjustment" of the controller did not occur.

The second major question treated is whether the times required for adaptation are practical. Directly related to the adaptation time is the problem of selecting the value of truncation time that will result in the fastest successful adaptation. The truncation time and the adaptation time are related because the total adjustment time is the product of the truncation time, the number of iterations (iterative adjustment to achieve adaptation), and a constant factor.

A truncation time of 3 sec gave successful adaptation with an average adaptation time of 57.5 sec.

WOLFE, J. R., "Ordering in Nickel-Manganese Alloys," M.S. in Metallurgical Engineering, 1960.

The ordering reaction in nickel-manganese alloys near the 50-50 composition was studied by means of electrical resistance, x-ray diffraction, and metallography. The transformation was followed by first quenching the alloys from a high temperature in order to retain the metastable disordered phase. The specimens were then reheated, and the ordering process was followed.

It was possible to analyze the kinetic data from the electrical resistivity measurements, in terms of a nucleation and growth equation. The metallography of the alloys clearly gives direct evidence that the ordering transformation takes place by nucleation and growth: it appears to be quite similar to a heterogeneous precipitation process. Data from x-ray diffraction data also confirm the nucleation and growth picture and indicate that there is an important strain or composition aspect in the transformation.

Notes and Comments

ENGINEERS IN THE NEWS

G. S. Smith, Professor of Electrical Engineering, who retired from the University this spring, has been named professor emeritus. Professor Smith has served at the University since 1921.

Scott Crossfield, research pilot for North American Aviation and test pilot for the X-15 experimental rocket plane, is a 1949 engineering graduate from the University. He holds B.S. and M.S. degrees in Aeronautical Engineering.

C. P. Costello, Assistant Professor of Mechanical Engineering, has been awarded a $9,500 NSF research grant. He will use the grant to study the effects of artificial high-gravity conditions, this study being a part of the search for information applicable to outer space.

Akira Ishimaru, Assistant Professor in Electrical Engineering, and **D. R. Dobrott,** graduate student, presented a paper entitled "East-West Effect on VLF Mode Transmission Across the Earth's Magnetic Field" at the URSI-IRE Meeting in Washington, D. C., on May 2-5.

RICHLAND CENTER NOW UNIVERSITY PROPERTY

The University has accepted from AEC a deed for six acres of land and property, including two two-story buildings, these being the facilities of the Hanford Center for Graduate Study. The University Graduate School is responsible for the administration of the Center, which since 1958 has been offering upper-division and graduate courses carrying University credit.

HYDRAULIC ENGINEERS AT UW

About 300 hydraulic engineers from the United States and Canada attended the ninth annual Hydraulics Division Conference of the American Society of Civil Engineers held August 17-19 on the UW campus. Subjects covered by papers included groundwater flow, tidal hydraulics, hydrology, flood control, sedimentation, and hydraulic structures.

ON ENGINEERING EDUCATION IN INDIA

Robert G. Hennes, Professor of Civil Engineering, writes that he finds his educational assignment to Bengal Engineering College at Calcutta "reasonably comfortable, highly interesting, and satisfying." As reported in the April *Trend,* Professor Hennes is to be in India for a year while he sets up a graduate program in soil mechanics.

These quotations are from Professor Hennes' letter to members of the UW Civil Engineering Department:

"Twice a week I have a 7:00-8:00 a.m. graduate soils class called 'bridge foundations.' At 6:50 the bearer appears at my office door, bearing the classbook, and eraser, and several pieces of chalk. Three paces behind me, he follows me through the senior drawing hall, downstairs to a small classroom equipped with tables and benches for about twenty students, blackboard, and two ceiling fans which he sets to whirling among the empty light sockets. He erases the board while the students stand at my entrance, and the day's work starts. There are only 7 or 8 in this group, but I also lecture weekly to two senior groups of sixty students each. I don't yet know the extent of the language barrier, but in every class I am aided by some stalwart individual or other who from time to time rises in his place and firmly announces 'not clear!' A couple of my trainees are starting next week to teach laboratory sections in soil mechanics, splitting the 120 seniors into eight sections for this purpose, each of which will meet biweekly. The lab is well equipped on the whole, and much of their British equipment (they have some nice Russian stuff in the applied mechanics lab) is superior to what we have in More Hall. They are short on the big machines. The students, selected from many thousands by competitive tests, are very sharp, but many a good prospective engineer may be eliminated by their emphasis on the IQ criterion . . .

"Afternoon classes run from 1:00 to 4:00. I have steered clear of afternoon classes to free my calendar for appointments and some of the other things that I am supposed to accomplish on this teacher-training graduate-research assignment that I have here, but my afternoons are not idle. My office is 15 by 25 feet, with 16-foot ceiling, starkly furnished with a desk, three chairs, and two small bookcases. At one end is a double door, and at the other double windows. I keep these all wide open, and the two ceiling fans going at good speed. This means that all papers have to be weighted down, and even light pamphlets have been known to fly about if left loose, but it enables me to work without discomfort despite the heat and humidity. The fans broke down for a spell this morning and in ten minutes I was wringing wet. The stroll across campus after work produces a heavy perspiration in any event, and once home I plop down in the air-conditioned living room, gradually reviving to a fair state of normalcy by the time that our 5 o'clock tea is trundled in . . ."

THE BEHAVIOR OF RIVETS

(Continued from page 14)

Action of Rivets Near the Ends of Cover Plates. From the information collected in this paper and from data collected during the initial tests on girders, some idea can be found of the action of rivets at the end of cover plates and of the manner in which they contribute to the development of the cover plate. This evaluation is illustrated in Fig. 6. The inclined line and the hatched area under it indicate the frictional resistance that can oppose the load and contribute in developing of the plate. The dotted line shows the rate at which the stresses built up in the middle cover plate at various stages of loading. This information was obtained from two strain gages fitted at distances of 8 in. and 16 in. from the end of the cover plate. In regions where the plates develop the stresses by friction alone, the inclination of the line representing the rate at which the stress builds up in the upper plate would be less than the limiting friction line shown in the figure. Any shearing or bearing action of the rivets would cause the line of stress development to acquire a slope greater than the line of limiting friction.

With uniform friction, a distribution of load to the outer cover plate should occur, but only when the cover plate elongates the same amount as the rest of the flange. This condition is evidently not possible at the end of the cover plate, where the flange carries the full load while the cover plate carries only a part of it. Such a situation forcibly starts a slip between the cover plate and the rest of the flange. This results in a change of coefficient of friction from its static value to its dynamic value, thereby putting the rivets in bearing and throwing a part of the load into areas that do not slip.

In this particular investigation, the information on the development of flange stresses is available for certain regions only, and the approach just explained can at best be used to analyze and interpret the structural action in those particular regions. In a more detailed investigation with a strain gage fitted between each row of rivets, more information can be checked.

As can be observed from Fig. 6, at design load the static friction is probably overcome, and the rivets start functioning in shear and bearing. A relative slipping of plates and redistribution of gaps in this region would, therefore, be anticipated, and a part of this slip could be expected to manifest itself at the ends of the cover plates as "unrecovered" or "residual slip" after unloading.

An examination of the surface of two rivets (Nos. 25 and 26) taken under the microscope from the end row of rivets of Specimen B revealed no evidence of stressing in the plastic range. This is contrary to what could be expected from the behavior of flanges noted at high loads, which causes the breaking of whitewash in the vicinity of rivet holes. Therefore we conclude that the clamping action of the rivet relieves it of a substantial part of the overstress.

Conclusions

In this investigation it has been observed that manufacturing processes leave gaps along the shank of the rivet and that considerable clamping force affects the behavior of a long riveted joint significantly. In fact, the behavior of riveted joints was very similar to that observed in large bolted joints at loads prior to the observation of any major slip in the bolted joint. As in a bolted joint, the friction between the plates resulting from the clamping force in rivets formed a significant factor in the action of the riveted joint. The static friction between plates was only overcome locally at the ends of plates, where evidence was discovered of the redistribution of gaps along the shank of the rivets.

It was also observed that, up to 2.13 times the design load, neither the end rivets nor the plates containing them suffered plastic deformation. This observation indicates that the clamping force in the rivet relieved a considerable part of the stress on the rivet by developing friction in the plates.

WHAT'S THE PRICE OF INFORMATION?

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THE POST-WELD THERMAL TREATMENT OF AN ALUMINUM-COPPER ALLOY

(Continued from page 20)

panied by the concomitant development of a highly depleted zone of ductile and easily deformable local environment. When a load is applied to such a structure, intense deformation occurs preferentially in the depleted zones, leading to extremely high stress concentrations at the interface between these zones and the highly undeformable brittle phase. Fracture is nucleated at this point and can progress rapidly through the entire weld structure.

It is apparent that a more detailed examination is required of the results obtained by aging in the critical time range between eight and twelve hours at 300° F and within proportionate times at other aging temperatures. The quantity of brittle phase present and the dimensions of the depleted zones should be determined so that brittle failure can be predicted on the basis of such microstructural data. This work has been started, and it is hoped that the results will be available in the near future.

ACKNOWLEDGMENT

The authors wish to express their gratitude to the Boeing Airplane Company for the privilege of using certain Boeing facilities and for permission to publish the data obtained.

PESTICIDES, SOURCE OF POLLUTION

(Continued from page 10)

tives), showed some degradation. Indications are that the side chains of various cyclic molecules are attacked, leaving the ring portions intact. Work is continuing on the relationship between pesticide structure and susceptibility to microbial decomposition.

In summing up, we have to recognize that pesticides have come to play an essential role in agricultural economics and environmental control, but that their full impact on the nation's water resources is not yet wholly understood. In light of recent experiences, it seems likely that further regulation and control of pesticide usage may be necessary in order to realize optimum water-resources development. Before such control is possible, however, a great deal more must be known regarding the behavior of pesticides in natural waters, particularly about their biochemical transformation and destruction.

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